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Business Impacts of Access Changes

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16. Abstract:

Some types of geometric improvements that the Virginia Department of Transportation (VDOT) has begun to build in the past two decades, such as the reduction in the number of arterial access points, the replacement of a traditional four-way intersection with a roundabout, or a restricted crossing U-turn, or left-turn prohibitions, have elicited expressions of concern from businesses that operate on property adjoining the improvements. The business operators' concern is that the improvement, by creating more circuitous access for motorists, will reduce customer traffic, with a consequent effect on the business's revenue or on the value of the affected commercial parcel. VDOT has never compiled a quantitative, Virginia-specific dataset on how access changes have affected adjacent businesses.

This study sought to fill that deficit by estimating the effects of changes in access on assessed parcel values before and after a VDOT reconstruction that altered the geometrics of an intersection or a road segment. Although business impacts could ideally be measured as taxable sales, such data were not feasible to obtain, and thus, assessed parcel values were the study focus. The study compiled information on 91 commercial properties fronting VDOT reconstruction projects, and on 67 similar commercial properties nearby, not fronting the projects, at 30 VDOT projects in 16 counties and three independent cities. Information collected included two different measures of the change in motorized access—the number of additional turns and additional distance traveled—that resulted from construction and assessed real estate values during a nine-year window from four years before the year construction was completed to four years after the year of construction completion. This nine-year window was sampled to have a strong opportunity to capture the lagged effects of changes in access in case such changes were not immediately reflected in project assessments. The analysis found that, within the nine-year window, the changes in access that the investigators measured had no statistically distinguishable effect on the property value assessments of the commercial properties fronting the VDOT reconstruction projects.

The analysis found some evidence of a small negative correlation between VDOT reconstruction work and the growth of assessed property value, via a relationship that the model employed in the study did not capture. When the commercial parcels were split into three groups of businesses, based on their expected sensitivity to access changes, this correlation was detected only in the two groups believed less likely to be sensitive. This correlation was not detected in the group expected to be most sensitive, such as gas stations, convenience stores, and fast-food restaurants.

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FINAL REPORT

BUSINESS IMPACTS OF ACCESS CHANGES

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In Cooperation with the U.S. Department of Transportation
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ABSTRACT

Some types of geometric improvements that the Virginia Department of Transportation (VDOT) has begun to build in the past two decades, such as the reduction in the number of arterial access points, the replacement of a traditional four-way intersection with a roundabout, or a restricted crossing U-turn, or left-turn prohibitions, have elicited expressions of concern from businesses that operate on property adjoining the improvements. The business operators' concern is that the improvement, by creating more circuitous access for motorists, will reduce customer traffic, with a consequent effect on the business's revenue or on the value of the affected commercial parcel. VDOT has never compiled a quantitative, Virginia-specific dataset on how access changes have affected adjacent businesses.

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FINAL REPORT

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INTRODUCTION

The Virginia Department of Transportation (VDOT) awards hundreds of contracts every year for improvements to the highway system the agency operates. As the funds available for these contracts are limited, it is essential to be able to predict and compare the relative benefits and costs of a "menu" of potential highway improvements. VDOT staff generally have good models, based on extensive historical data, to predict a project's up-front construction cost. VDOT staff generally have good models to predict the impacts of an improvement on travel time, vehicle operating costs, crash risk, and pollutant emissions within the area where the improvement's effect is felt.

VDOT staff have no model and relatively little information, however, to predict the business impacts on commercial establishments that adjoin the new facilities when a highway investment changes traveler access to one or more parcels that adjoin the highway. Business impacts may be reflected as changes in customer traffic, property values, sales prices, tax revenue, or rents. This lack of data is felt because questions about a shift in customer traffic arise in both public hearings and in right-of-way negotiations. Two reasons for research now on forecasting the quantitative business impacts that result from changes in traveler access to commercial parcels are (1) the passage of Virginia Senate Bill 666 in 2022 and (2) the recent removal of a restricted crossing U-turn (RCUT) intersection reconstruction project from the Six-Year Improvement Plan due to public opposition that hinged in part, ostensibly, on their expected effect on customer traffic.

Senate Bill 666

In 2022, Senate Bill 666 amended §§25.1-100 and 25.1-230.1 of the Code of Virginia to redefine "lost profits" for a business or farm operation for the purpose of determining just compensation in an eminent domain proceeding. This legislation is expected to have a significant effect on the cost of right-of-way acquisition, already one of the least predictable elements of project cost. It is therefore expected to affect the cost estimates in planning studies and the recommendations that emerge from these studies (LegiScan, 2022; Trackbill, 2022).

VDOT planning studies consider various designs, traditional or innovative, to address operations and safety issues. Reduction of traffic conflict points, one safety consideration in many planning studies, often leads toward a design that modifies the motorized access to a commercial or agricultural property fronting the road. Senate Bill 666 increases the likelihood that a VDOT planning study that addresses traffic conflicts will have to assess the effect each potential design will have on neighboring properties.

Unanswered Questions about Restricted Crossing U-Turns

A shift in customer traffic between one establishment and another does not register as a *net* benefit or cost to the community that the highway network serves. A standard benefit-cost analysis of a highway project will not capture this effect. Nonetheless, such a shift in customer traffic can matter greatly to the owner or renter of an individual real estate parcel.

A recent safety project in Pittsylvania County, involving the construction of an RCUT in the place of a previously existing four-way signalized intersection, made its way to the public hearing stage of development, even into the Department's Six-Year Improvement Plan, only to be withdrawn later in the face of opposition from the local government (Hunziker, 2023; Mirza, 2023; Wilborn, 2023). The public hearing for a similar RCUT project in Gloucester County received multiple negative comments, leading the county board of supervisors to vote against it (Bass, 2023). This sort of opposition is not unique to RCUTs. A proposed roundabout design in Halifax County was withdrawn partly because of concerns about the effect on businesses fronting the affected VDOT right-of-way (Fitzwater, 2024). VDOT seeks stakeholder opinion as a matter of policy and attempts to address concerns raised at public hearings. That being said, to pull a project late in the design stage means that effort has been wasted on a "dead-end" project and that a solution to the problem the project was designed to remedy is going to be delayed.

Stakeholders at local meetings raised questions about a variety of effects that the transformation from four-way signalized to RCUT might entail. The safety and operational effects have been well documented at the national level (Bared, 2009) and are also explained in VDOT publications (VDOT, 2023). In the face of questions about the impact on customer traffic at commercial establishments adjoining the intersection, however, VDOT staff recognized a need for more information about the range of possible effects and the factors that determine their size.

An Illustration of a Change in Motorized Access

For some vehicles moving through an intersection, the conversion from four-way to RCUT affects access to properties at the corners of the intersection (Federal Highway Administration, n.d.). Figure 1 shows that compared with a four-way intersection, the RCUT forces northbound left-turning vehicles to follow a more circuitous and time-consuming path to reach the business.

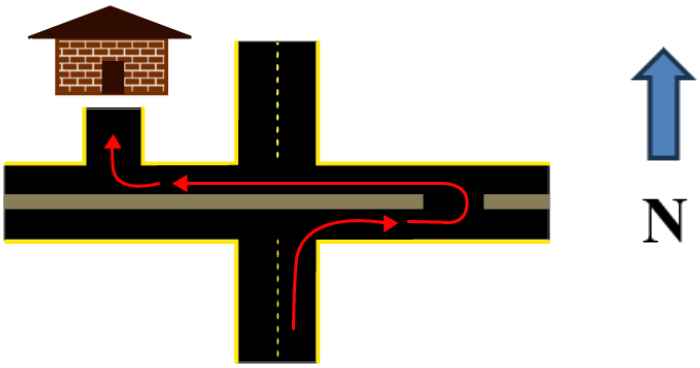

Figure 1. Northbound Traffic Seeking to Access a Business

Problem Statement

The recent pushback against RCUTs may partly arise from the traveling public's unfamiliarity with their design, a factor that may diminish naturally with time if VDOT continues to build them. However, RCUTs are only one type of reconstruction that alters motorized access. Businesses express concerns about other types of access changes, such as median closures. Thus, the problem facing VDOT is that the effects of changes in motorized access on businesses is not known. This problem applies to a wide variety of reconstruction projects beyond RCUTs.

This lack of knowledge can be felt in at least two points of the transportation planning and project development process. One is in discussions with the public, which may occur through required public hearings but also through optional (non-required) information meetings in which members of the public provide input on a variety of project alternatives. The second point is in right-of-way acquisition, for which VDOT staff need supporting information when engaging with property owners whose property will undergo a change in motorized access. In both cases, having better information about the business impacts of changes in access can improve the discussion of project alternatives.

PURPOSE AND SCOPE

The purpose of this study was to estimate the effect a commercial establishment can expect when a VDOT reconstruction project changes motor vehicle access to the establishment's property. Three primary considerations determined the study scope:

- The study was confined to VDOT reconstruction projects, in order that the findings might be based on Virginia-specific data.
- The study sample included multiple types of geometric improvements, in order that the sample size might be larger and the findings might be sufficiently general to have relevance for multiple types of improvements.
- The two definitions of motorist access that were selected to measure the changes in access were calculable using only the data available.

METHODS

The research approach consisted of five sequential steps that culminated in a calibrated Virginia business impacts model as the final step.

1. Conduct a literature review.
2. Propose a business impacts model.
3. Identify Virginia sites.
4. Collect data.
5. Develop the business impacts model.

Literature Review

VDOT has begun in recent years to introduce several new intersection designs into the Commonwealth of Virginia's highway network. The roundabout is one of the older, more frequently constructed innovative designs (Carlton, 2024). VDOT has adopted several other newer designs into its toolkit (VDOT, 2018).

Publications that study the association between highway geometrics and customer behavior are not numerous and thus do not, by themselves, meet the research need. However, they provide useful starting points for the remaining four methods used in this study.

Motorized Access

Kennedy (2019) identified "vehicle ingress and egress" as one of the location factors that can influence the value of a commercial parcel. The same author identified "transportation"—meaning transit, cyclist, and pedestrian access in this case—and "surrounding property"—that is, proximity to potential customers—and "traffic count" as location factors that can influence the value of a parcel.

Huffman (2023) discussed the trade-offs that may hinge on the choice of access connections to private commercial property and off-site improvements in the vicinity of the property. Access connections and off-site improvements may affect accessibility, safety, mobility, and aesthetics, and each of these may affect the market value of a parcel.

Plazak and Preston (2005) reported the findings of a study funded by the Minnesota Department of Transportation that modeled the economic impacts of converting a high-speed, at-grade arterial known as Trunk Highway 12, or U.S. Highway 12, to a freeway-standard facility renamed Interstate 394. This road, connecting downtown Minneapolis with the western suburbs of the Twin Cities metropolitan area, was reconstructed from 1985 to 1993. Commercial parcels, which formerly were entered directly from the arterial, were afterward entered via new frontage roads on either side of the reconstructed freeway. The investigators compiled several before and after measures of economic conditions, including (1) the number of businesses, (2) the rate of business turnover, (3) gross retail sales, including taxable services, (4) employment, and (5) commercial land values. The investigators also interviewed a representative sample of 14 business owners on the U.S. Highway 12-Interstate 394 corridor. During the study period from

1984 through 2004, land use shifted from residential space to retail space and to office and service sector space, and traffic on the road roughly doubled. In other words, the corridor was urbanizing. The study found that the highway reconstruction met its primary objectives: adding traffic capacity, preserving flow, and improving safety "dramatically." Furthermore, the study found that the statistical indicators of business conditions generally showed growth at or above the average for the metropolitan area and the state as a whole. Individual business owners who were interviewed gave mixed responses: two fast-food restaurants reported a positive trend in sales after the reconstruction; two big-box retail stores reported a positive trend in sales after the reconstruction; and a handful of sit-down restaurants, some of them affected by right-of-way acquisition, expressed fears beforehand about the effects both on their visibility and their accessibility from the highway. That said, these establishments continued to operate at the same locations after the reconstruction but reported that the new system of frontage roads confused customers, especially first-time customers. Two auto dealerships, also affected by the right-of-way acquisition, expressed the same fears beforehand about visibility and accessibility from the highway. That said, both dealerships remained at the same locations as of 2005. A gas station continued to operate at the same location after the reconstruction. Plazak and Preston (2025) noted incidentally in their introduction, "Although the safety and traffic flow benefits of access management have been well-documented …, the literature on the impacts of access management projects on adjacent commercial businesses and land parcels is much less abundant."

Hodge (2024) described a similar methodological approach to evaluate the effect of "complete streets" investments in a sample of Massachusetts towns. Complete Streets policies entail geometric modifications and other changes. The consequences for motor vehicle access are not necessarily positive because the policies' goal is to balance and, to the extent possible, enhance safety and access for travelers by *all* modes—transit, motor vehicle, bicycle, and foot traffic. The investigators measured the economic impact of the complete streets modifications using three measures: the change in property values in the affected neighborhood, the change in the number of jobs, and the change in the number of commercial establishments. The study found a detectable positive effect on property values in two of the towns studied, a negative effect in one town, and an impact indistinguishable from zero in two towns. In response to a question after the presentation, the presenter stated that the investigators certainly would have loved to use retail sales figures as a measure but were not able to obtain them.

Innovative Intersections

Schneider et al. (2019) obtained before and after sales tax receipts at the intersection level to compute average customer traffic before and after construction of an RCUT, also referred to as a J-turn. They collected these data for ten intersections in four study locations in the state of Louisiana. The investigators found no decrease in taxable sales between the two-year period before the improvements and the two-year period after but rather a slight overall increase.

Miller (2020) conducted a preliminary exploration of the business impacts of access changes to inform VDOT colleagues who were fielding questions about the new RCUT intersection design. This memorandum identified some of the likely challenges to data collection. Miller had to rely on impact measurements from other states because the newness of RCUTs made it nearly impossible to collect both before and after data from Virginia RCUT projects. The

memorandum reviewed published information from other states as of 2020 and extracted some tentative conclusions for application in Virginia.

Barnes et al. (2022) obtained data from four intersections adjoining commercial parcels, two intersections adjoining industrial parcels, and four intersections adjoining residential parcels. The investigators adopted four separate approaches to measuring the empirical impact and the perceived effect of conversion from a signalized intersection to an RCUT intersection: (1) night-time radiance data, a proxy measure of economic activity on each parcel; (2) a survey of the neighboring businesses, as a measure of commercial neighbors' perceptions; (3) residential real estate sale prices, as a measure of the road user benefits (or costs) capitalized into the price of nearby parcels; and (4) a survey of nearby residents. The radiance data delivered "mixed results with most models resulting in a null effect." The business survey data suggested that commercial properties that received many late-afternoon customers expected the most positive impacts, and industrial properties expected the most negative impacts. The analysis of residential real estate prices delivered mixed results. The survey of residents indicated that residents were willing to "pay" for safety with added wait time at the intersection but that the residents revealed a stronger dislike of added time waiting to turn left than their dislike of added time to their commute as a whole. The investigators interpreted this revelation to mean that the residents, as drivers, preferred traffic that continues to *flow*. The North Carolina Department of Transportation (2023) refers to RCUTs as "reduced conflict intersections," or "RCIs".

Kimley-Horn (2024), in cooperation with VDOT staff, conducted case studies of ten recently constructed innovative intersections in the Commonwealth of Virginia. Four of the intersections were remade as RCUTs, three as unsignalized or continuous-green "T" intersections, two as quadrant roadways, and one as a partially displaced left turn. The investigators examined the before and after crash data at these locations as a measure of the impact on safety. They examined the mean travel speed before and after as a measure of the impact on traffic flow. The investigators also interviewed businesses adjacent to or close to the reconstructed intersections to assess the effect of the new geometries. The investigators' success rate in obtaining responses slightly exceeded 50%: of the 28 approached, 15 responded. Most businesses reported either positive or neutral impacts on customer traffic after reconstruction. One convenience store and two hotels reported a negative impact on customer traffic.

A Georgia study, underway at the time of this writing, will examine "any associated changes to economic performance of the impacted businesses nearby" following the construction of RCUTs. Study GA RP 24-12, funded by the Georgia Department of Transportation (2025), managed by Sabbir Ahmed, and conducted by Yichang Tsai, was initiated in January 2025 and is expected to be completed in October 2026.

Other Literature

Uncertainty about the business impacts of access to the parking lots of the businesses fronting the road has prolonged the process of reaching a satisfactory design decision for a few specific VDOT projects. Lantz, Jr. et al. (2008) reported findings from interviews with VDOT staff involved in the project scoping process. "Interviewees gave a range of answers for the duration of project scoping, but all answers were between 3 and 6 months." Scoping is part of the

preliminary engineering (PE) phase of the project delivery process. Miller and Turner (2014) reported that, from 2004 to 2012, the percentage of pooled VDOT project costs spent on PE ranged from 11.2% to 18.8%. When one evaluates the risk that uncertainty about the impact of access changes will prolong the PE phase of project delivery and considers the possibility that additional information about the impact can reduce this risk, these baseline estimates of the duration and cost of PE may be kept in mind.

Summary of Inferences from the Literature

The literature provided four insights that affected how the remaining methodology should be applied.

- Most studies have used only a small number of sites, so one contribution would be to find a way to increase the sample size beyond just a few sites.
- The choice of what attribute to measure—sales tax data, property sales data, business turnover, or surveys of customers or proprietors—is influenced by the ease or difficulty of obtaining the data element, and all have been used as proxies for customer traffic.
- Different types of geometric changes, such as RCUTs or simple median closures, can be represented in some way as a change in access.
- The effect of other factors that change at the same time that access changes, such as economic conditions, should be considered in a study.

A Proposed Business Impacts Model

To build a model of the impact of a change in motorized access on customer traffic, one must assemble several pieces. First, one must obtain one or more direct or indirect measures of customer traffic. Second, one must obtain one or more direct or indirect measures of motorized access, the factor whose effect on customer traffic is to be tested. Third, one would also like to obtain measures of the other uncontrolled factors that may influence customer traffic.

Choice of Customer Traffic Measures

An Ideal Measure: Taxable Sales

Several indicators of economic activity are available to measure the impact on business properties. Schneider et al. (2019) used taxable sales, a relatively direct measure of customer traffic. Barnes et al. (2022) used (1) night-time radiance, (2) survey responses from neighboring businesses, and (3) the price of nearby parcels. The first and third of these indicators may be expected to be correlated with customer traffic, and the second may be expected to reflect the perception or expectation of an effect on customer traffic.

As business owners expressed fear of lost sales in the public meetings, sales records seemed the first and best measure of business impact. The investigators made inquiries with the Virginia Department of Taxation regarding the possibility of obtaining historical taxable sales records under terms compliant with the Virginia tax rules for preserving taxpayer confidentiality.

These inquiries eventually received a regretful but definitive negative answer (Michael Palmer, "personal communication," December 5, 2023; Palmer, 2024).

A Surrogate Measure: Real Estate Assessments

VDOT's Right-of-Way Division consults certain indirect measures of attractiveness to customers during their preparations for negotiations and court proceedings to determine the value of a real estate taking. Two examples of these indirect measures are (1) the amount of rent generated by an arm's-length lease agreement and (2) the appraised value of the parcel.

Given that taxable sales are out of consideration, the investigators opted for real estate assessments. These assessments are public records, available at the level of the individual commercial parcel. The reasoning that underlies the use of real estate values as a proxy for customer sales holds that if a superior location attracts above-average sales, some fraction of the above-average net revenue that the resident business anticipates will be capitalized into the rent, or into the asking price, of the real estate (Kennedy, 2019). If a change in motorized access makes a commercial parcel's location more or less favorable, then the rent or the price of the parcel may reflect that change.

However, at the very outset of this study, the technical review panel provided the investigators with feedback on the behavior they expected of real estate assessments. Technical review panel members expected real estate assessments not to react quickly to changes in highway geometry. Any value movement, other than movement on trend with the neighborhood, was likely to become manifest only when the parcel, or a comparable neighboring parcel, changed hands at a recorded price (Randall Snow, "personal communication," October 7, 2023). Thus, a way to address this lag was required.

Interviews with Real Estate Appraisers

To better understand the strengths and weaknesses of real estate appraisals for this study, the investigators held conversations, either by telephone or e-mail, with four persons in four different Virginia county assessors' offices, each familiar with the appraisal practices in that county and sometimes with practices in other counties as well (Collier, "personal communication," August 4, 2025; Foster, "personal communication," August 6, 2025; Kilby, 2025; Liggan, 2025).

The investigators also spoke with one fee appraiser, familiar with the practices in appraisals performed for customers such as mortgage lenders, real estate developers, or estate executors (Will Sanford, "personal communication," August 4, 2025). Because they intended to use real estate assessments to measure customer traffic indirectly in a regression model, the investigators sought to understand the behavior over time that they might expect to see in real estate assessments.

The first question was, "Would a change in parking lot access, resulting from a reconstruction of the road geometrics, in and of itself induce your appraisers to revise the estimated value of a commercial parcel?" The county assessors said that their appraisers

generally would *not* revise assessments based solely on geometric change; they would wait to see if a property sale revealed a change in value. The fee appraiser said that a fee appraisal might possibly take into account a change in the ease of ingress and egress. The fee appraiser and two of the county assessors mentioned spontaneously that, for occupants of commercial parcels, visibility tended to be a more important location factor than simplicity of access.

The second question was, "Would a change in traffic volume on the road fronting the parcel induce your appraisers to revise the estimated value of a commercial parcel?" The county assessors said that they would indeed expect traffic volume to influence a parcel's value. Nonetheless, they said that their appraisers would tend to wait for a property sale to confirm their expectation. The fee appraiser said that a fee appraisal quite likely would consider a change in traffic volume.

Summary: The Need for a Time Lag in the Model

The expectations of the county assessors matched the expectations of the technical review panel. The expected behavior of real estate assessments as a measure of customer traffic provided a strong rationale for building and estimating a mathematical model that allowed for a response with a possibly substantial time lag. This consideration stood somewhat in conflict with the fact that long observation periods "after completion" were not going to be available for many of the VDOT projects of interest because many of the innovative intersections had been constructed so recently. The investigators opted to model a four-year time window beyond the year containing the project completion date to increase the likelihood of capturing the lagged effects of changes in access.

Choice of Access Measures

The investigators sought to build a model that could conduct an apples-to-apples comparison of the impact of access changes caused by a wide variety of reconstruction projects. To achieve this goal, the investigators opted for measures of access change that transcended specific project types and specific highway geometries.

Given the origin of the research question, in fears expressed by business operators or their supporters that the change in access would affect customer traffic, the investigators sought measures of access change that would capture the point of view of the potential customer who might or might not choose to pull into the parking lot of a certain business establishment. To achieve this goal, the investigators opted for measures of access change that the operator of a motor vehicle would experience directly as an annoyance.

The investigators defined two primary measures of a change in access.

- A driver approaching from a given direction might be influenced by the number of turning movements that he or she must execute to enter the parking lot of the affected commercial parcel.
- A driver approaching from a given direction might be influenced by the distance that he or she must travel to enter the parking lot of the affected commercial parcel.

The explanatory power of the before and after measures of motorized access in the statistical analysis would constitute the finding that answers the research question. Figure 2 illustrates how the measures of change in access would be computed.

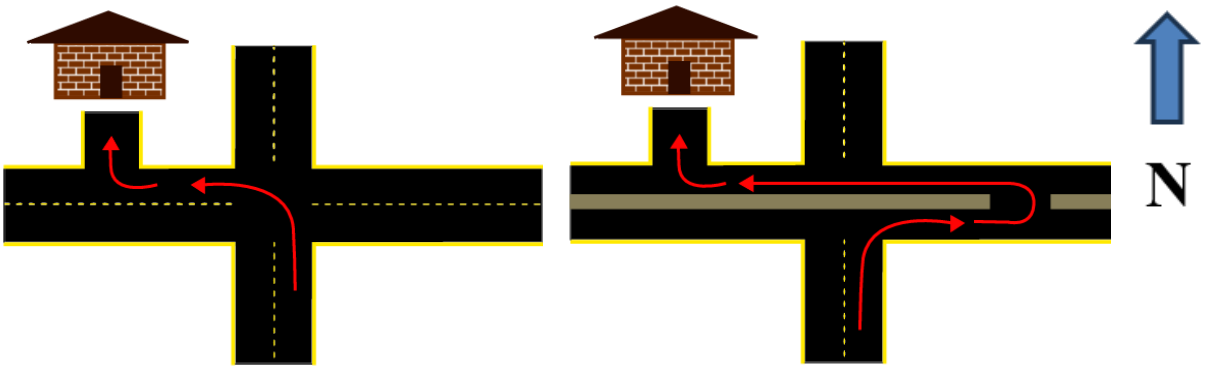

Figure 2. Example of Access Changes. (Left) Before reconstruction, northbound traffic requires 0.1 miles and two maneuvers—a left turn to the westbound lane and then a right turn into the parking lot. (Right) After reconstruction, northbound traffic requires 0.3 miles and three maneuvers—a right turn to the eastbound lane, a U-turn, and then a right turn into the parking lot.

The investigators added a third explanatory variable, a treatment group dummy variable, which would carry a value of one (1) for every parcel that fronted on a VDOT reconstruction project and would carry a value of zero (0) for every parcel that did not. The reasoning behind this choice was that, although the investigators believed their measures of access change were realistic and intuitively compelling, they wanted to allow for the possibility that VDOT reconstruction work could affect customer traffic through an unknown causal mechanism, which their measures of access change failed to capture. If that were the case, the treatment group dummy might capture it. This variable was not a measure of change in access specifically but rather a proxy for any factor—population growth, traffic congestion, crash risk, or other influences—that might happen to be correlated with both VDOT reconstruction work and the appeal of a commercial location.

The investigators considered another way to define and measure access change: a driver approaching from a given direction might be influenced by the travel time required to enter the parking lot of the affected commercial parcel. The investigators ultimately rejected this measure. For one thing, measurement of the travel time requirement would require more elaborate traffic modeling. For another, the travel time requirement would not necessarily be evident to a driver approaching the commercial establishment. By contrast, the two measures selected could be calculated by visual inspection of the before and after road geometrics using data sources such as plans, and a driver approaching the commercial establishment would likely perceive them.

Choice of Control Variables

Three other factors were identified that, in addition to ease of motorized access, could influence the value of a parcel: the business type, local trends in real estate values, and trends in local traffic volumes.

Business Types

The type of commercial enterprise that operates on an affected real estate parcel may make a difference. One might suppose that the businesses most vulnerable to changes in access would be establishments that depend on spontaneous customer visits, such as gas stations, convenience stores, and fast-food restaurants. These enterprises tend to attract customer visits that are not planned far in advance — possibly not before the driver hits the road. These enterprises also tend to have competitors, offering similar goods and services, only a short drive away. The investigators grouped the commercial establishments in their sample into three business type categories.

1. Gas stations, convenience stores, and fast-food (drive-through) restaurants. Customer traffic at these businesses was expected to be most sensitive to a change in motorized access.
2. Sit-down restaurants (possibly offering carry-out but not offering drive-through), hotels, grocery stores, pharmacies, and banks. Customer traffic at these businesses was expected to be less sensitive to a change in motorized access.
3. All other establishments, including variety retailers (e.g., Walmart and Target), smaller variety stores (e.g., Dollar General), shopping centers, healthcare offices, and education establishments. Providers of automotive goods and services other than fuel also fell in this category. As visits to these establishments are usually planned, customer traffic at these businesses was expected to be least sensitive to a change in motorized access.

Trends in Local Real Estate Values

The investigators wanted to control for the influence of locality-wide factors such as population growth that might have an independent effect on assessed real estate values. The Virginia Department of Taxation (2025) publishes an annual *Assessment Sales Ratio* that reports in its Table 4 estimates of the total fair market value in each county and city, and data from 1998 to 2023 were used for this study. These estimated totals do not match the totals that one would obtain if one summed the assessed values in the county record office. However, they are highly correlated and readily accessible. The investigators included these countywide estimates as a control variable.

Trends in Local Traffic Volumes

Geometric modifications of the roadway are believed to affect customer traffic at business establishments that front the roadway by affecting the inclination of passing motorists to pull into the parking lot. Changes over time in traffic volume, as they would change the size of the "pool" of potential customers, would presumably also change the amount of spontaneous customer traffic. The investigators included the average annual daily traffic (AADT) for each direction approaching the intersection or segment that was reconstructed.

Identify Virginia Sites

The investigators built their database around two lists of projects provided by members of the technical review panel: innovative intersections and those requiring right of way.

The first of these sources was a list of 32 "innovative intersections," assembled by VDOT's Innovative Intersections Task Group and brought to the investigators' attention by the Transportation Mobility Planning Division (TMPD). This list included reconstructions of traditionally configured intersections to one of seven different more-or-less innovative designs: the quadrant roadway intersection, the (partial) displaced left turn intersection, the (unsignalized) continuous green T intersection, the RCUT, the diverging diamond intersection, the jughandle intersection, or the single-point urban interchange.

The second source was a list of 26 projects brought to the investigators' attention by VDOT's Right-of-Way Division (RWD). These projects included some element of right-of-way acquisition, typically also the construction of a median where one was not previously present. The investigators elicited a couple of additional suggestions from the VDOT district offices.

The commonality between these two sources is that the change in access may affect how a customer accesses a parcel. From the former source, an example is the replacement of the signalized intersection at Mountain Run Lake Road and U.S. Highway 29 in Culpeper with an RCUT. This change required drivers on the minor road who intended a through movement or a left-turn movement to turn right at the center of the intersection and then make a U-turn at a location on the major road 100 yards from the center of the intersection. From the latter source, an example is the reconstruction of the interchange at U.S. Highway 29 and Rogers Road (State Route 666), also outside Culpeper. The construction on Rogers Road of long stretches of median, where none existed previously, similarly precluded some left turns, increasing the maneuvers required for vehicles to access some of the neighboring businesses.

Data Collection

The investigators began compiling their database with two lists of projects provided by technical review panel members from TMPD and RWD. During the early months of this study, the investigators also took advantage of statewide meetings to solicit additional suggestions from VDOT district office planning staff, location and design staff, and traffic engineering staff. These "publicity efforts" included a meeting of the Innovative Intersections Task Group on August 15, 2023, the District Planners' Meeting on August 24, 2023, and a Transportation Planning Research Advisory Committee meeting on October 27, 2023. Two important considerations in data collection were the sample size and the data sources.

Sample Size

The sample consisted of a treatment group of commercial parcels close enough to one of the VDOT projects to experience a possible direct effect on motorized access and a control group of commercial parcels in locations similar to those of the treatment group parcels but far enough from the VDOT projects to avoid a direct effect on motorized access.

The Treatment Group

The treatment group was a sample of commercial parcels fronting VDOT projects that met the following criteria:

1. The construction or implementation of the project resulted in geometric changes that affected access to real estate fronting the reconstructed road segments.
2. Before and after observations that afforded measurement of motorized access to the neighboring real estate parcels were available.
3. Before and after observations that afforded measurement of the change in assessed value of the neighboring real estate parcels were available.

The availability of both before and after observations proved to be a significant constraint. At some reconstructed intersections, the neighboring commercial parcels were not developed until after reconstruction, so no before observations were available. Some of the most recently constructed innovative intersections, on the other hand, were too new to allow the collection of after observations.

The Control Group

The control group was a sample of commercial parcels that met the following criteria:

1. The parcel occupied a location relatively close to the location of one or more parcels in the treatment group.
2. The business that operated on the parcel fell in the same business type category as one or more of the parcels at the nearby VDOT project location.
3. Before and after observations that afforded measurement of the change in assessed value of the real estate parcels were available.

Figure 3 illustrates the heuristic method used to identify comparable commercial parcels for the control group. A road segment that VDOT reconstructed in Powhatan County is near the map's center. A Bojangles restaurant at 1850 Stavemill Crossing Lane is close to the VDOT project, which may affect the restaurant. This location is at the origin of the route shown in blue in Figure 3. A search for nearby restaurants finds Frisby's Restaurant at 2150 Anderson Highway, 1.5 miles west of the VDOT project and presumably not directly affected by the VDOT project. This location is the red "thumbtack" icon at the destination end of the route shown in blue. Bojangles is a fast-food restaurant in the first business type category, and Frisby's is a sit-down restaurant in the second business type category, which is not a perfect comparison but usefully close.

Table 1 shows that 91 treated parcels and 67 control parcels were included in the study sample.

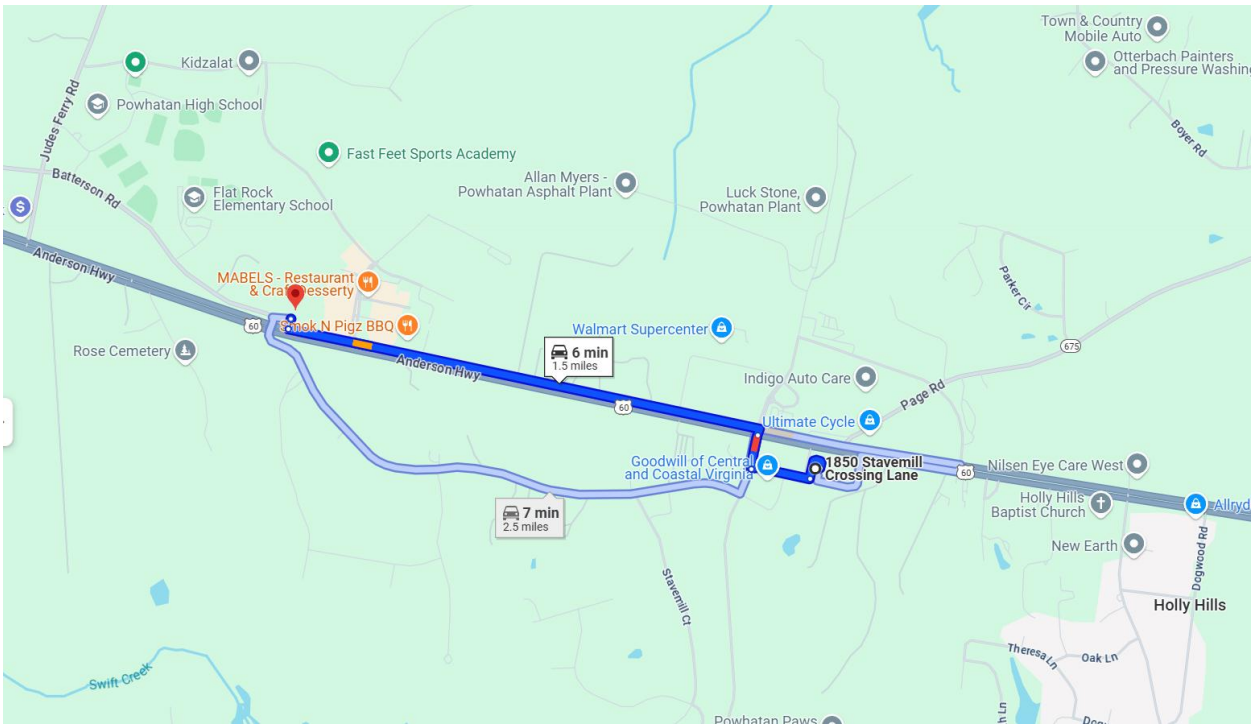

Figure 3. Screenshot from the Google Maps Website, Requested to Provide Directions from 1850 Stavemill Crossing Lane to 2150 Anderson Highway. ©Google Maps, May 23, 2025.

Table 1. Number of Sites

	Business Type 1[a]	Business Type 2[b]	Business Type 3[c]	Total
Treatment	20	14	57	91
Control	19	14	34	67
Total	39	28	91	158

[a] Expected to be most sensitive to access changes (e.g., gas stations). [b] Expected to be less sensitive to access changes (e.g., grocery stores). [c] Expected to be least sensitive to access changes (e.g., healthcare offices).

Choices and Consequences in Filtering the Dataset

Lacking taxable sales records, the investigators had to rely on property tax records and aerial photographs to determine that a business was operating during the window from four years before to four years after the completion of a reconstruction project. The choices they made in implementing this approach had two consequences. First, they accepted some reduction in sample size and some downward bias in the average growth of real estate assessments in exchange for a focus on businesses that operated in the same building throughout the observation period at each project. Second, the investigators accepted some additional heteroscedasticity in the sample in exchange for a greater sample size and broader coverage.

When available tax records and photographs indicated that the business commenced operations after the completion of VDOT reconstruction—for example, if an aerial photograph showed that the building on the parcel was not constructed until the completion date or later—the investigators excluded the commercial parcel in question. This exclusion was a debatable choice. Had this study focused on measuring economic development, clearly the right choice for the investigators would have been to include parcels on which buildings were removed or

constructed. Exclusion of commercial parcels on which building removal or construction occurred during the time window around the completion of a VDOT project imparted a strong downward bias to the average change in assessed real estate value. The parcels where removal or construction had occurred were those where economic development was most obvious, and they tended to be the parcels whose assessed values rose the most. In fact, this study focused on the effect VDOT work had on existing businesses that continued to operate. With this purpose, the investigators restricted the sample to parcels on which the same business continued to operate in the same building.

When the available documentation indicated that the business commenced operation at least one year before the completion of reconstruction, the investigators included the commercial parcel in question. In some cases, in which property tax assessments could not be obtained for a full four years before or a full four years after VDOT construction, the investigators included a parcel with a truncated window of seven or eight years of data, rather than nine years. This concession, too, was a debatable choice. It certainly introduced some extra heteroscedasticity into the sample because one could not assume that an average annual growth rate during a six- or seven-year interval contained the same amount of statistical "noise" as an average annual growth rate during a eight-year interval. On the other hand, this concession obtained a larger sample with more coverage in terms of both sheer numbers and geographic representation.

Additional Summary Sample Statistics

Additional summary data from the projects that the investigators examined provide an impression of the frequency with which VDOT undertakes projects that change the geometrics of a road segment or intersection in a way that changes motorized access to adjoining real estate. They also provide an impression of the amounts of PE and right-of-way expenditures that VDOT has made on reconstruction projects of this sort.

The investigators were able to obtain completion dates or estimate them for 48 of the projects that came to their attention. They were able to identify the commercial parcels adjoining the same 48 projects. Table 2 shows the distribution of projects by their recorded or estimated year of completion. As shown, most of the projects in the sample were completed in 2017, 2018, 2019, or 2020, with the largest number of 11 completed in 2017. The projects that were completed sufficiently long ago to be eligible for the regression analysis come from 2009 to 2022. During this 14-year period, the average number of projects per year averages three.

Table 2. Distribution of Projects, by Year of Completion

Completion Years	2009–2013	2014	2015	2016	2017	2018	2019	2020	2021–2022	2023 or Later
Number of projects	4	2	2	2	11	5	8	7	4	3

Table 3 shows the distribution of projects by the number of commercial parcels identified as fronting each of these 48 projects. The number four was an arbitrary cap rather than a theoretical limit on the number of commercial parcels that a VDOT reconstruction project may affect. The investigators sampled no more than four treatment group commercial parcels from any single VDOT project, although the geometric changes that the project wrought might have

extended to the frontage of more than four parcels. It is evident, all the same, that the majority of the VDOT projects in the sample adjoined fewer than four commercial parcels that happened to contain an existing business. Eight of the VDOT projects that met the investigators' criteria were fronted by no existing businesses at all. The average number of existing businesses fronting these 38 projects was 2.4. The 30 projects represented in the statistical analysis in Table 3 exclude the eight that were fronted by no existing businesses and exclude several more that were excluded because of data shortcomings.

Table 3. Distribution of Projects, by Number of Active Commercial Parcels that Fronted Them

Number of Active Commercial Parcels	0	1	2	3	4
Number of projects	8	5	9	12	14

The investigators were able to obtain final cost figures for 38 of the projects that came to their attention. The distribution of PE expenditures for these 38 projects was markedly skewed, with a long right-hand "tail." The minimum PE expenditure was zero, the median PE expenditure was $2,000,000, the average was $2,974,000, and the maximum expenditure was $14,127,000. The distribution of right-of-way expenditures was even more strongly skewed. The minimum right-of-way expenditure was zero, the median expenditure was $3,310,000, the average was $8,650,000, and the maximum was $90,898,000. These expenditures are not inflated, so the older PE figures understate the purchasing power they would represent at 2025 prices. The same consideration applies to the right-of-way expenditure figures. On the other hand, because only an unidentified small fraction of the right-of-way totals was devoted to the acquisition of commercial real estate, the right-of-way expenditures likely overstate the amount of right-of-way expenditure that could possibly be sensitive to the change in motorized access that the reconstruction project causes.

Both the frequency distribution and the PE expenditure estimates must be considered undercounts for three reasons. First, these summary statistics unquestionably omit a few VDOT reconstruction projects that came to the investigators' attention but whose costs the investigators failed to retrieve. Second, they unquestionably omit recent projects, which the investigators excluded because they recognized they would not be able to collect sufficient "after" data. Third, these summary statistics almost certainly omit some projects that would have met the criteria for this study but never came to the investigators' attention.

Data Sources

For each VDOT project, the construction completion date was obtained, when possible, from the six-year improvement program in the iSYP or the Project Pool database. In some cases, when the requisite date was lacking, the completion date was estimated from another date in iSYP that was not lacking. In a few cases, the completion date was inferred from the sequence of year-stamped aerial photographs of the location available in Google Earth.

For each VDOT project, the before and after geometries were obtained, when possible, from plans available in the ProjectWise library. In many cases, the sequence of aerial photographs available from Google Earth confirmed the geometries. In a few cases, when plans were unavailable, the aerial photographs provided the before and after geometries.

For each commercial parcel, assessed real estate values for four years before the year of completion to four years after the year of completion were obtained from the tax office in the county or city of the parcel location.

For each commercial parcel in the treatment group, the annual estimates of total fair market value in the surrounding county from four years before to four years after the relevant VDOT work were obtained from the Virginia Department of Taxation's (2025) annual *Assessment Sales Ratio* publications. For each parcel in the control group, the annual estimates of total fair market value in the surrounding county were likewise obtained for the years covering the period from four years before to four years after the VDOT work at the nearest parcel in the treatment group.

For each commercial parcel in the treatment group, the AADT volume from four years before completion to four years after completion was retrieved from the VDOT Traffic Monitoring Program (VDOT, 2025). For each parcel in the control group, AADT was retrieved for the years covering the period from four years before to four years after the VDOT work at the nearest parcel in the treatment group. The number of AADT volumes tabulated each year would equal the number of approaches at the intersection. Reconstruction of a four-way intersection would require tabulation of four AADT volumes each year from the four approaches, reconstruction of a three-way intersection would require tabulation of three AADT volumes each year, and reconstruction of a road segment would require the tabulation of two AADT volumes each year.

Development of the Business Impacts Model

Ordinary least squares regression in this study posits a functional relationship $\Delta PV_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \varepsilon_i$, where ΔPV_i is a dependent variable of interest (in this case, the change in parcel values over time), x_{1i} and x_{2i} are independent variables whose values one can use to predict the value of ΔPV_i, and ε_i is a random "error" that follows a Gaussian distribution, whereas β_0, β_1, and β_2 are parameters to be estimated. Under these assumptions, choosing the parameter estimates of b_0, b_1, and b_2 that minimize the sum of squared errors $\Sigma(\Delta PV_i - b_0 - b_1 x_{1i} - b_2 x_{2i})^2$ amounts to choosing the parameter estimates that maximize the likelihood of observing the set of observations $(\Delta PV_1, x_{1\text{-}1}, x_{2\text{-}1})$, $(\Delta PV_2, x_{1\text{-}2}, x_{2\text{-}2})$, …, $(\Delta PV_{159}, x_{1\text{-}159}, x_{2\text{-}159})$ where 159 observations (i.e., 159 parcels) are in the dataset. In other words, an ordinary least squares estimate is also a maximum-likelihood estimate if the errors (the influences unmodeled) are truly Gaussian.

Equation 1—The Log-Log Equation

Equation 1 represents the first regression model that was estimated, where the dependent variable—$\Delta \ln PV_i$—is the change in the logarithm of the assessed value of the parcel.

$$\Delta \ln PV_i = \beta_0 + \beta_1 \cdot \Delta \ln Avg_i + \beta_2 \cdot \Delta \ln \Sigma AADT_{ij} + \beta_3 \cdot \Sigma \Delta T_{ij} + \beta_{31} \cdot \delta_{1i} \cdot \Sigma \Delta T_{ij} + \beta_{32} \cdot \delta_{2i} \cdot \Sigma \Delta T_{ij} + \beta_4 \cdot \Sigma \Delta D_{ij} + \beta_{41} \cdot \delta_{1i} \cdot \Sigma \Delta D_{ij} + \beta_{42} \cdot \delta_{2i} \cdot \Sigma \Delta D_{ij} + \beta_5 \cdot TG_i + \beta_{51} \cdot \delta_{1i} \cdot TG_i + \beta_{52} \cdot \delta_{2i} \cdot TG_i + \varepsilon_i \quad \text{(Equation 1)}$$

Where:
i indexes the parcels.
j indexes the approaches to each parcel.
t indexes the year of completion of VDOT work neighboring each parcel.
k, used in the following definitions but not in Equation 1, indexes the years.

β_0, β_1, β_2, β_3, β_{31}, β_{32}, β_4, β_{41}, β_{42}, β_5, β_{51}, and β_{52} are parameters to be estimated.

$\Delta\ln PV_i$ is a real number equal to the natural logarithm of the ratio between the assessed value of parcel i four years after completion of VDOT work, t+4, and the assessed value four years before, t-4, divided by the eight years, the length of the observation period (i.e., $\Delta\ln PV_i = \ln(PV_{i,t+4} / PV_{i,t-4})/8$). The 8 may be explained as supposing a project is completed in 2015, such that years 2011, 2012, 2013, and 2014 are the before period, and years 2016, 2017, 2018, and 2019 are the after period. Eight yearly changes occur between the first and last observations, beginning with 2011–2012 and ending with 2018–2019. In some cases in which the earliest retrievable value was from a year later than t-4 or the latest retrievable value was from a year earlier than t+4, the divisor would be smaller than 8.

$\Delta\ln Avg_i$ is a real number equal to the natural logarithm of the ratio between the county average estimated total market value of real estate in the county where parcel i is located, four years after completion of VDOT work, t+4, and the county average estimated total market value of real estate four years before, t-4, divided by eight years, the length of the observation period (i.e., $\Delta\ln Avg_i = \ln(Avg_{i,t+4} / Avg_{i,t-4})/8$). In some cases in which the latest retrievable estimate was from a year earlier than t+4, the divisor would be smaller than 8.

$\Delta\ln\Sigma AADT_{ij}$ is a real number equal to the average annual growth rate of the natural logarithm of the sum of AADT on all legs of approach to the intersection or segment on which VDOT worked, from four years before completion of the work, t-4, to four years after completion, t+4 (e.g., the slope of the regression line through the logarithms of the nine sums $\Sigma AADT_{i,j,k}$). Because the AADT time series were somewhat more volatile than the assessed value time series or the estimated total market value time series, especially during the COVID-19 pandemic, the investigators opted to compute the average growth rate not simply by computing the average rate between the first and last years but rather by regressing the natural logarithms of the total AADT volumes in each of the nine years against the year numbers. The slope of the resulting regression line through the log values of AADT, although still sensitive to changes in the first- and last-year values, was less sensitive than the $\Delta\ln PV_i$ and $\Delta\ln Avg_i$ computations would have been.

$\Sigma AADT_{i,j,k}$ is the sum of the AADT volumes at intersection i over all directions of approach j during all years from year k=t-4 to year k=t+4.

$\Sigma\Delta T_{ij}$ is a whole number equal to the weighted average of $\Delta T_{i,j}$ over all directions of approach j, the weights being the AADT on each approach as a fraction of total AADT on all approaches.

$\Delta T_{i,j} = T_{i,j,t+1} - T_{i,j,t-1}$ is a whole number equal to the change in the number of turns required for a vehicle approaching from direction j to enter the parking lot of parcel i from the year before completion of VDOT work, t-1, to the year after, t+1.

$\Sigma\Delta D_{ij}$ is a real number equal to the weighted average of $\Delta D_{i,j}$ over all directions of approach j, the weights being the AADT on each approach as a fraction of the total AADT on all approaches.

$\Delta D_{i,j} = D_{i,j,t+1} - Distance_{i,j,t-1}$ is a real number equal to the change in the distance (in thousands of feet) that a vehicle approaching from direction j must travel to enter the parking lot of parcel i from the year before completion of VDOT work, t-1, to the year after, t+1.

TG_i is a dummy variable that equals one (1) if parcel i belongs to the treatment group and zero (0) if parcel i belongs to the control group.

δ_{1i} is a dummy variable that equals one (1) if parcel i belongs to the Business Type 1 category and zero (0) if parcel i does not belong to that category.

δ_{2i} is a dummy variable that equals one (1) if parcel i belongs to the Business Type 2 category and zero (0) if parcel i does not belong to that category.

ε_i is a random normal variable—i.e., an error term—unique to parcel i.

Note that t is the year of construction completion. Therefore, the observation period captured nine annual observations, from the year four years before completion (t-4) to the year four years after completion (t+4). For the purposes of computing rates of change, the observation period spanned eight years.

Equation 2—The Log-Log Equation that Omits the Business Type Categories

To assess the sensitivity of the results to changes in the model specification, the investigators ran alternative regressions that involved fewer variables or a different functional form. Equation 2 represents the second regression model that was estimated. Once again, the dependent variable, ΔPV_i, is the change in the assessed value of the parcel.

$$\Delta PV_i = \beta_0 + \beta_1 \cdot \Delta Avg_i + \beta_2 \cdot \Delta\Sigma AADT_{ij} + \beta_3 \cdot \Sigma\Delta T_{ij} + \beta_4 \cdot \Sigma\Delta D_{ij} + \beta_5 \cdot TG_i + \varepsilon_i, \quad \text{(Equation 2)}$$

The symbols represent the same variables as defined for Equation 1, but the business type dummy variables are omitted. This omission pools all commercial parcels into a single group rather than into three separate business type groups, imposing the restriction that all business establishments, regardless of type, be assumed to have the same sensitivity to changes in motorized access.

Comparing the results of regressing Equation 1 and regressing Equation 2 on the same dataset affords a test of the importance, if any, of the distinction among the three categories of businesses.

Equation 3—The Linear Equation

Equation 3 represents the third regression model that was estimated. The dependent variable, ΔPV_i, is the change in the assessed value of the parcel.

$$\Delta PV_i = \beta_0 + \beta_1 \cdot \Delta Avg_i + \beta_2 \cdot \Delta\Sigma AADT_{ij} + \beta_3 \cdot \Sigma\Delta T_{ij} + \beta_{31} \cdot \delta_{1i} \cdot \Sigma\Delta T_{ij} + \beta_{32} \cdot \delta_{2i} \cdot \Sigma\Delta T_{ij} + \beta_4 \cdot \Sigma\Delta D_{ij} + \beta_{41} \cdot \delta_{1i} \cdot \Sigma\Delta D_{ij} + \beta_{42} \cdot \delta_{2i} \cdot \Sigma\Delta D_{ij} + \beta_5 \cdot TG_i + \beta_{51} \cdot \delta_{1i} \cdot TG_i + \beta_{52} \cdot \delta_{2i} \cdot TG_i + \varepsilon_i \quad \text{(Equation 3)}$$

Equation 3 closely resembles Equation 1. The three terms that are different are ΔPV_i, ΔAvg_i, and $\Delta\Sigma AADT_{ij}$. These terms are defined as follows.

> ΔPV_i is a real number equal to the eighth root of the ratio between the assessed value of parcel i four years after the completion of VDOT work, t+4, and the assessed value four years before, t-4, the eighth root being taken because eight years is the length of the observation period (i.e., $\Delta PV_i = (PV_{i,t+4} / PV_{i,t-4})^{1/8}$). In some cases in which the earliest retrievable value was from a year later than t-4 or the latest retrievable value was from a year earlier than t+4, the root taken would be the seventh or the sixth, rather than the eighth, so the power shown in the equation would be ⅐ or ⅙ rather than ⅛.
>
> ΔAvg_i is a real number equal to the eighth root of the ratio between the county average estimated total market value of real estate in the county where parcel i is located, four years after the completion of VDOT work, t+4, and the county average estimated total market value of real estate four years before, t-4, the eighth root being taken because eight years is the length of the observation period (i.e., $\Delta Avg_i = (Avg_{i,t+4} / Avg_{i,t-4})^{1/8}$). In some cases in which the latest retrievable estimate was from a year earlier than t+4, the root taken would be seventh or the sixth.
>
> $\Delta\Sigma AADT_{ij}$ is a real number equal to the average annual growth rate of the sum of AADT on all legs of approach to the intersection or segment on which VDOT worked, from four years before the completion of the work, t-4, to four years after completion, t+4 (e.g., the slope of the regression line through the nine sums $\Sigma AADT_{i,j,k}$). As in Equations 1 and 2, the investigators opted to compute the average growth rate not simply by computing the average rate between the first and last years but rather by regressing the total AADT volumes in each of the nine years against the year numbers.
>
> $\Sigma AADT_{i,j,k}$, as before, is the sum of the AADT volumes at intersection i over all directions of approach j during all years from year k=t-4 to year k=t+4.

Equation 1 above expresses the average growth rate of assessed value between year Y–4 and the year Y+4 as a *rate of increase* between the value in one year and the value in the following year. This number will be slightly greater than zero if the growth rate is positive and

slightly less than zero if the growth rate is negative, rather than as the natural logarithm of that ratio. By contrast, Equation 3 expresses the average growth rate of assessed value as a *ratio* between the value in one year and the value in the previous year. This number will be slightly greater than one if the growth rate is positive and slightly less than one if the growth rate is negative. Likewise, Equation 3 expresses the average growth rate of the estimated true market value of real estate in the county as a ratio rather than as a rate of increase and, so likewise, the growth rate of the total AADT on the approach legs of the intersection. Equations 1 and 3 are both *ad hoc* specifications. The investigators have no strong theoretical grounds to prefer one over the other. Comparing the results of regressing Equation 1 and regressing Equation 3 on the same dataset will provide a basis for judging which of the two—the log-log specification, Equation 1, or the linear specification, Equation 3—is a better fit to the available data.

RESULTS

The investigators generated three sets of regression results: the first regression with all variables (Equation 1), a second regression equation with a smaller number of variables (Equation 2), and a third regression equation that used the linear functional form (Equation 3) rather than the logarithmic form.

First Regression with All Variables

Table 4 lists the full results of the first regression. The first column indicates the parameters from Equation 1. The second column indicates the explanatory variable to which each parameter β corresponds. The third, fourth, fifth, and sixth columns show the point estimate, standard error, t-statistic, and p-value, respectively, for each parameter in the model.

Table 4. Regression 1 Results[a]

Parameter	Variable	Point Estimate	Standard Error	t-statistic	P-Value (2 tails)
β_0	Intercept term	0.00536	0.00946	0.56641	0.57198
β_1	County mean real estate appreciation	0.37047	0.13406	2.76354	0.00645
β_2	Local traffic volume	– 0.15694	0.09705	– 1.61723	0.10799
β_3	1st access measure: number of turns	0.00804	0.01445	0.53413	0.55666
β_{31}	Bus. Type 1 × 1st access measure	0.01553	0.05065	0.30663	0.75956
β_{32}	Bus. Type 2 × 1st access measure	– 0.00330	0.03940	– 0.08373	0.93338
β_4	2nd access measure: travel distance	0.01625	0.01234	1.31687	0.18995
β_{41}	Bus. Type 1 × 2nd access measure	– 0.05867	0.04178	– 1.40437	0.16233
β_{42}	Bus. Type 2 × 2nd access measure	– 0.01366	0.05115	– 0.26715	0.78973
β_5	Occurrence of reconstruction dummy	– 0.00990	0.00616	– 1.60676	0.11027
β_{51}	Bus. Type 1 × reconstruction dummy	0.01325	0.01032	1.28382	0.20124
β_{52}	Bus. Type 2 × reconstruction dummy	– 0.01190	0.01127	– 1.05552	0.29293

Bus. = Business. [a] The model shown in Table 4 explained 14.41% of the variation in the change in assessed parcel values. The sum of squared residuals equaled 0.15171 with 146 degrees of freedom.

The statistical estimates of the parameters β_3, β_{31}, β_{32}, β_4, β_{41}, β_{42}, β_5, β_{51}, and β_{52} address the research question: the β_3s as a group measure the sensitivity of assessed property values to changes in the number of turns required; the β_4s as a group measure the sensitivity to the travel

distance required; and the β_5s as a group measure the correlation between assessed values and the occurrence of VDOT reconstruction work.

The statistical estimates of the parameters β_0, β_1, and β_2 do not address the research question directly, but they improve model fit and thereby facilitate the estimation and interpretation of the above parameters. The first parameter, β_0, allows for the regression line to cross the y-axis at the point that affords the best fit to the observed data. The second parameter, β_1, accounts for the countywide trend in real estate prices to ensure that this trend does not obscure the influence of the access measures. The third parameter, β_2, similarly accounts for the neighborhood-wide trend in local traffic volumes to ensure that this trend does not obscure the influence of the access measures.

The interpretation of Table 4 is based on the following seven sets of parameters:

- R-squared statistic.
- Intercept.
- The coefficient for county mean real estate appreciation.
- The coefficient for local traffic volume growth.
- The coefficients for the first access measure (number of turns).
- The coefficients for the second access measure (travel distance).
- The coefficients for the occurrence of reconstruction.

The R-Squared Statistic

The rather small value of the R-squared statistic indicates that other factors, besides those compiled in this study and displayed in Table 4, have a big influence on the change in a parcel's assessed value.

Intercept

The t-statistic of the constant term β_0 estimate indicates that the estimate does not differ significantly from zero. The constant term has to do only with the "fit" of the regression equation. Neither the magnitude nor the sign of the constant term affects the evaluation of the motorized access measures.

County Mean Real Estate Appreciation

β_1 is the coefficient on the change in the county total estimated fair market value. The countywide changes in fair market value were expected to serve as a baseline against which variations due to local effects, such as VDOT roadwork, would stand out. This estimate has a positive sign, suggesting that the assessed values of the parcels in the sample group tend to increase as the fair market value of the average parcel in the county rises, as would be expected. The estimate of the coefficient on this variable differs from zero with a fairly high level of statistical significance. The p-value indicates that an estimate this large in magnitude would have only a 1.66% probability of occurring if the true value of the coefficient were zero. This estimate does not affect the evaluation of the motorized access measures.

Local Traffic Volume Growth

β_2 is the coefficient on the change in the sum of AADT on all legs of approach for which recorded traffic volumes were retrievable. In a few cases, the investigators were unable to retrieve AADT on the minor road of an intersection. The countywide changes in fair market value were expected to account for influences on commercial parcel value that would be felt countywide. The changes in AADT were expected to account for the influence of traffic volume growth—that is, greater exposure to potential customers—that would be felt locally. The investigators supposed that this influence would be largely independent of the influence of the geometric change that the VDOT reconstruction work effected. In fact, the point estimate of the coefficient for this explanatory variable is negative. The p-value associated with this estimate indicates that an estimate of this magnitude would have an 11.17% probability of occurring if the true value were zero, so the estimate borders on statistical significance. Again, however, this estimate does not affect the evaluation of the motorized access measures.

First Access Measure (Number of Turns)

The parameters β_3, β_{31}, and β_{32} apply to the access measure "change in number of turns required." This access measure constituted an attempt to capture the motorist's perception of the complexity of the maneuver that he or she must make to enter an establishment's parking lot. The estimates of these coefficients provide no evidence that a commercial parcel's real estate assessment is sensitive to a change in the number of turns required to access the parcel. Table 5 displays the interpretation of these parameters for commercial parcels of the first, second, and third business types.

Table 5. Results for First Access Measure: Change in Required Number of Turns

Parameter	Variable[a]	Point Estimate	Standard Error	T-statistic	P-Value (2 tails)
$\beta_3+\beta_{31}$	Coefficient on 1st access measure when business type is 1	0.02358	0.05267	0.44760	0.32755
$\beta_3+\beta_{32}$	Coefficient on 1st access measure when business type is 2	0.00475	0.04196	0.11309	0.45506
β_3	Coefficient on 1st access measure when business type is 3	0.00804	0.01445	0.55666	0.57861

[a] The first access measure is the change in the number of turns required to access the parcel.

For commercial parcels in the Business Type 1 category, the businesses expected to be most sensitive to changes in access, the implied coefficient is $\beta_3 + \beta_{31} = 0.02358$, the sum of the coefficient on the change measure *plus* the coefficient on the change measure times the Business Type 1 dummy. For commercial parcels in the Business Type 2 category, the less sensitive businesses, the implied estimate is $\beta_3 + \beta_{32} = 0.00475$, the sum of the coefficient on the change measure plus the coefficient on the change measure times the Business Type 2 dummy. For commercial parcels in the Business Type 3 category, non-sensitive businesses, the implied estimate is $\beta_3 = 0.00804$, the coefficient on the change measure alone.

The point estimates imply that an increase in the number of turns that a motorist must make to enter a commercial establishment's parking lot tends to have a *positive* impact on the

parcel's assessed value. The low t-statistics and correspondingly high p-values indicate that each of these estimates has a fairly high probability—32.76%, 45.51%, or 57.86%—of occurring by chance, however, even under the null hypothesis that the true coefficients equal zero.

Second Access Measure (Travel Distance)

The parameters β_4, β_{41}, and β_{42} apply to the access measure "change in required travel distance." This access measure constituted an attempt to capture the motorist's perception of how far out of the way he or she must drive to enter an establishment's parking lot. Table 6 displays the interpretation of these parameters for commercial parcels of the first, second, and third business types.

Table 6. Results for Second Access Measure: Change in Required Travel Distance

Parameter	Variable[a]	Point Estimate	Standard Error	T-statistic	P-Value (2 tails)
$\beta_4+\beta_{41}$	Coefficient on 2nd access measure when business type is 1	– 0.04243	0.04356	– 0.97389	0.16586
$\beta_4+\beta_{42}$	Coefficient on 2nd access measure when business type is 2	0.00258	0.05261	0.04911	0.48045
β_4	Coefficient on 2nd access measure when business type is 3	0.01625	0.01234	1.31687	0.18995

[a] The second access measure is the change in distance required to access the parcel.

For commercial parcels in the Business Type 1 category, the businesses expected to be most sensitive to changes in access, the implied coefficient is $\beta_4 + \beta_{41} = -0.04243$, the sum of the coefficient on the change measure *plus* the coefficient on the change measure times the Business Type 1 dummy. For commercial parcels in the Business Type 2 category, the businesses expected to be less sensitive, the implied coefficient is $\beta_4 + \beta_{42} = 0.00258$, the sum of the coefficient on the change measure plus the coefficient on the change measure times the Business Type 2 dummy. For commercial parcels in the Business Type 3 category, the businesses expected to be non-sensitive, the implied coefficient is $\beta_4 = 0.01625$, the coefficient on the change measure alone.

The point estimates imply that an increase in the distance a motorist is required to drive to reach a commercial parcel's parking lot would have a small positive impact on the assessed value of a parcel that houses a Business Type 1 establishment (gas station, convenience store, or fast-food restaurant), a small negative impact on the assessed value of a parcel that houses a Business Type 2 establishment (sit-down restaurant, hotel, grocery store, pharmacy, or bank), and a small positive impact on the assessed value of a parcel that houses a Business Type 3 establishment (all other kinds of enterprises). However, the t-statistics and the p-values indicate that each of these estimates has a fairly high probability—16.59%, 48.05%, or 19.00%—of occurring by chance, even under the null hypothesis that the true coefficient is zero.

Occurrence of Reconstruction

The parameters β_5, β_{51}, and β_{52} apply to the backup explanatory variable, the treatment group dummy. This explanatory variable was intended to capture any association between VDOT reconstruction and property values which the previous two access measures failed to

capture. Table 7 displays the interpretation of these parameters for commercial parcels of the first, second, and third business types.

Table 7. Results for Treatment Group Dummy

Parameter	Variable[a]	Point Estimate	Standard Error	T-statistic	P-Value (2 tails)
$\beta_5+\beta_{51}$	Coefficient on 3rd access measure when business type is 1	0.00335	0.01202	0.27876	0.39041
$\beta_5+\beta_{52}$	Coefficient on 3rd access measure when business type is 2	– 0.02180	0.01285	– 1.69684	0.04593
β_5	Coefficient on 3rd access measure when business type is 3	– 0.00990	0.00616	– 1.60676	0.11027

[a] The treatment group dummy takes a value of one if the parcel adjoined a VDOT reconstruction project that made geometric changes that could affect motor access and zero if the parcel did not.

For commercial parcels in the Business Type 1 category, the businesses expected to be most sensitive, the implied coefficient in Table 5 is $\beta_5 + \beta_{51} = 0.00088$, the sum of the coefficient on the treatment group dummy *plus* the coefficient on the treatment group dummy times the Business Type 1 dummy. For commercial parcels in the Business Type 2 category, the businesses expected to be less sensitive, the implied coefficient is $\beta_5 + \beta_{52} = -0.02440$, the sum of the coefficient on the change measure plus the coefficient on the change measure times the Business Type 2 dummy. For commercial parcels in the Business Type 3 category, the businesses expected to be non-sensitive, the implied coefficient is $\beta_5 = -0.00990$, the coefficient on the change measure alone.

The point estimates imply that VDOT construction work, via some mechanism that the model applied in this study did not capture, has a tiny positive correlation with the assessed value of a parcel that houses a Business Type 1 establishment. However, the t-statistic and the p-value indicate that the estimate of the sum $\beta_5 + \beta_{51}$ has a fairly high probability of occurring by chance, 39.04%, even under the null hypothesis that the true coefficient is zero. The point estimates imply that VDOT construction work, via some mechanism that the model applied in this study did not capture, has a small negative impact on the assessed value of a parcel that houses a Business Type 2 or 3 establishment. The t-statistics and p-values indicate that the estimate of the sum $\beta_5 + \beta_{52}$ and the estimate of β_5 alone have relatively low probabilities of occurring by chance under the null hypothesis, 4.59% and 11.03%, respectively.

It is notable, perhaps surprising, that Types 2 and 3 businesses, those believed to rely little on unplanned visits by passing motorists, would exhibit a detectible correlation with the presence of VDOT reconstruction, and Type 1 businesses would not.

One Numerical Example that Illustrates the Mechanics of the Regression Model

This subsection will use the regression results to *estimate* the change in the assessed real estate value of one parcel in the dataset, a parcel occupied by a grocery retailer in Saluda, Virginia, a Food Lion at 12532 Tidewater Trail. This computation will illustrate the contribution that each term in Equation 1 makes to the total value of the dependent variable.

A VDOT project completed in 2015, project number 103461 in the Supplemental Materials, involved the reconstruction of the intersection of Tidewater Trail (U.S. Highway 17) and General Puller Highway (U.S. Highway 17 Business) in Saluda. Before the reconstruction, westbound vehicles on General Puller Highway were permitted to pass straight through the intersection to enter the store's parking lot on the other side. They also were permitted to turn left into the southbound lane of Tidewater Trail. Northbound vehicles on Tidewater Trail were permitted to make left turns into the store's parking lot, and southbound vehicles on Tidewater Trail were permitted to make left turns onto General Puller Highway heading east. After the reconstruction, a low concrete wall created a physical barrier between northbound vehicles turning left from Tidewater Trail into the store's parking lot on the west side of the road and southbound vehicles turning left from Tidewater Trail onto General Puller Highway eastbound. This wall *prevented* westbound vehicles on General Puller Highway from proceeding straight through the intersection to the store parking lot. In the future, these drivers wishing to enter the parking lot would have to turn right onto Tidewater Trail, turn left at a cut in the median about 360 feet further north, and enter the parking lot there. The wall also prevented vehicles from turning left from General Puller Highway into the southbound lane of Tidewater Trail, although this prohibition affected no neighboring commercial parcels.

For each term in Equation 1, the first, second, third, and fourth columns in Table 8 show the symbol representing the variable, the common name of the variable, the symbol representing the coefficient on the variable, and the estimated value which the regression assigns to the coefficient. The fifth, sixth, and seventh columns show the range of values—lowest, median, and highest—that each variable takes across the range of all parcels in the dataset. The eighth column shows the specific value of each variable for the parcel at 12532 Tidewater Trail in Saluda.

The ninth column shows the product of the estimated coefficient times the variable value. Each of these products is one of the terms in Equation 1. The sum of these 12 terms is the average annual growth rate of assessed value, which the regression *estimates* for the parcel at 12532 Tidewater Trail. The regression residual is the difference between the true growth rate of the assessed value and this estimate.

The prohibition of left turns and straight-through movements at the intersection from the minor road (General Puller Highway) means that vehicles coming from General Puller Highway must make more turns and travel a longer distance to enter the Food Lion parking lot. The first access measure, the change in the number of turns, $\Sigma\Delta T_{ij}$, therefore shows a positive change. The second access measure, change in travel distance, $\Sigma\Delta D_{ij}$, therefore shows a positive change. Because the example parcel adjoins an intersection that VDOT reconstructed, the parcel is a member of the treatment group, not the control group. Therefore, the treatment group dummy TG_i has a value of one (1).

The business that operates on the example parcel is a grocery store. By the investigators' definition this business falls into the Business Type 2 category. For this parcel i, therefore, the business type dummy δ_{1i} has a value of zero and the business type dummy δ_{2i} has a value of one. The fact that δ_{1i} equals zero explains why the interaction terms $\delta_{1i}\cdot\Sigma\Delta T_{ij}$ and $\delta_{1i}\cdot\Sigma\Delta D_{ij}$ and $\delta_{1i}\cdot TG_i$ each have a value of zero. The fact that δ_{2i} equals one explains why the interaction terms

$\delta_{2i} \cdot \Sigma\Delta T_{ij}$ and $\delta_{2i} \cdot \Sigma\Delta D_{ij}$ and $\delta_{2i} \cdot TG_i$ have values equal to the terms $\Sigma\Delta T_{ij}$ and $\Sigma\Delta D_{ij}$ and TG_i, respectively.

Table 8. Computation of the Estimated Change in Assessed Value from Year t-4 to Year t+4.

Variable Symbol	Variable Common Name	Para-meter Symbol	Para-meter Estimate	Variable Lowest Value	Variable Median Value	Variable Highest Value	Example Parcel Value	Additive Term in Eq. 1
	Constant term	$\beta 0$	0.00536	(1)	(1)	(1)	(1)	0.00536
ΔAvg_i	County mean real estate appreciation	β_1	0.37047	– 0.01357	0.05799	0.08630	– 0.01357	– 0.00503
$\Delta\Sigma AADT_{ij}$	Local traffic volume	β_2	– 0.15694	– 0.06805	– 0.00232	0.07179	0.00996[a]	– 0.00151
$\Sigma\Delta T_{ij}$	1st access measure: no. of turns	β_3	0.00804	– 0.45143	0	1.81505	0.22353	0.00180
$\delta_{1i} \cdot \Sigma\Delta T_{ij}$	Bus. Type 1 × 1st access measure	β_{31}	0.01553	– 0.18436	0	0.61538	0	0
$\delta_{2i} \cdot \Sigma\Delta T_{ij}$	Bus. Type 2 × 1st access measure	β_{32}	– 0.00330	0	0	0.91837	0.22353	– 0.00074
$\Sigma\Delta D_{ij}$	2nd access measure: travel distance	β_4	0.01625	– 1.20780	0.000	2.58244	0.06147	0.00100
$\delta_{1i} \cdot \Sigma\Delta D_{ij}$	Bus. Type 1 × 2nd access measure	$\beta 41$	– 0.05867	– 0.11735	0.000	0.54763	0	0
$\delta_{2i} \cdot \Sigma\Delta D_{ij}$	Bus. Type 2 × 2nd access measure	$\beta 42$	– 0.01366	– 0.13842	0.000	0.46633	0.06147	– 0.00084
TG_i	Treatment group: reconstruction	$\beta 5$	– 0.00990	0	1	1	1	– 0.00990
$\delta_{1i} \cdot TG_i$	Bus. Type 1 × Treatment group	$\beta 51$	0.01325	0	0	1	0	0
$\delta_{2i} \cdot TG_i$	Bus. Type 2 × Treatment group	$\beta 52$	– 0.01190	0	0	1	1	– 0.01190
ΔPV_i	**Change in assessed value**			**– 0.13572**	**0.01996**	**.20565**	**– 0.00033**	**– 0.02181**

Bus. = Business; Eq. = equation. [a] For the nine years from Y-4 to Y+4 (2011–2019 in this case), the combined average annual daily traffic volumes on the three legs approaching the intersection totaled 7,700, 8,000, 8,050, 8,100, 85,00, 8,500, 8,550, 8,350, and 8,300. The natural logarithms of these nine totals were taken and regressed against the year numbers (2011, …, 2019). The slope of the resulting regression line is the growth rate shown in Table 8, which is -0.00996. This computation, rather than the simpler one used to compute the dependent variable ΔPV_i and the independent variable ΔAvg_i, was adopted for the reasons noted in the Development of the Business Impacts Model subsection of this report's Methods section.

The terms in the ninth column sum to make the *estimated* annual growth rate of assessed value for the parcel in question, shown near the lower right corner of Table 8. The last box in the eighth column shows the *actual* growth rate of assessed value for the parcel in question. The

growth rate which the regression predicts for this particular parcel is an underestimate of the actual growth rate: –0.02044 versus the true –0.00033.

Recall that this change in assessed value, shown as ΔPV_i, is the natural log of the annual change in assessed value (e.g., $\ln(PV_{i,t+4} / PV_{i,t-4})/8$). Thus, the forecast is exp(-0.02181) = 0.98, indicating that the model forecasts the assessed value would drop 2% per year. In reality, the true change was exp(-0.00033) = 0.9997, meaning that the assessed value dropped 0.03% per year.

The Second, More Restrictive Regression Model

Table 9 lists the full results of the second regression. The first column indicates the parameters from Equation 2. The second column indicates the explanatory variable to which each parameter β corresponds. The third, fourth, fifth, and sixth columns show the point estimate, standard error, t-statistic, and p-value, respectively, for each parameter in the model.

Table 9. Regression 2 Results[a]

Parameter	Variable	Point Estimate	Standard Error	t-statistic	P-Value (2 tails)
β_0	Intercept term	0.00524	0.00939	0.55820	0.57753
β_1	County mean real estate appreciation	0.37265	0.13284	2.80520	0.00569
β_2	Local traffic volume	– 0.16630	0.09468	– 1.75648	0.08102
β_3	1st access measure: number of turns	0.00922	0.01246	0.73974	0.46060
β_4	2nd access measure: travel distance	0.01297	0.01089	1.19130	0.23539
β_5	Treatment group: reconstruction	– 0.01069	0.00540	– 1.97977	0.04953

[a] The model shown in Table 9 explained 11.49% of the variation in the change in assessed parcel values. The sum of squared residuals equaled 0.15688 with 152 degrees of freedom.

The statistical estimates of the parameters β_3, β_4, and β_5 address the research question. Comparing with Equation 1 shows that Equation 2 imposes the six restrictions that the parameters β_{31}, β_{32}, β_{41}, β_{42}, β_{51}, and β_{52}, which were free to take non-zero values in Equation 1, must equal zero in Equation 2. In other words, Equation 2 does not allow for the possibility that some business types may be more or less sensitive to changes in access than others. Because Equation 2 requires the estimation of six fewer parameters, the regression leaves 152 degrees of freedom instead of 146.

The first three rows of results in Table 9 show that the estimates of the parameters β_0, β_1, and β_2 are largely unaffected by the restriction on the other three parameters.

The estimates of the parameters β_3, β_4, and β_5, now restricted to be the same across all business types, take on values that resemble comparatively closely the values that Table 4 showed for Business Type 3, the most numerous group of parcels in the dataset. The estimates of the coefficients on the first and second access measures remain not statistically distinguishable from zero. The p-values indicate that the estimate of β_3, which reflects the effect of a change in the number of turns required, has a magnitude that could be expected with 46.06% probability even if the coefficient had a true value of zero, and the estimate of β_4, which reflects the effect of a change in the travel distance required, has a magnitude that could be expected with 23.54% probability. The estimate of β_5, which reflects some link between VDOT work and assessed value that the access measures in the model did not capture, also takes on a value close to the

value seen for Business Type 3 in Equation 1 and has a magnitude that could be expected with a probability of only 4.95% if the coefficient's true value were zero.

An F statistic, based on a comparison between the sum of squared residuals from the first regression and the sum of squared residuals from the second regression, provides a test of the hypothesis, embodied in Equation 2, that the extra six restrictions in Equation 1 are not binding: that is, that the parameters β_{31}, β_{32}, β_{41}, β_{42}, β_{51}, and β_{52} in Equation 1 truly equal zero, so that the same parameters β_3, β_4, and β_5 apply to businesses of all three types. This F statistic, with 6 and 146 degrees of freedom, has a value of 0.82942, implying a p-value of 0.45106. In other words, an F statistic this big has a 35.52% chance of occurring even if the restrictions are not binding. For this dataset, at least, the null hypothesis that businesses of all types are equally sensitive to the access measures and to the treatment group variable cannot be rejected.

The Third, Linear Regression Model

Table 10 lists the full results of the third regression. The first column indicates the parameters from Equation 3. The second column indicates the explanatory variable to which each parameter β corresponds. The third, fourth, fifth, and sixth columns show the point estimate, standard error, t-statistic, and p-value, respectively, for each parameter in the model.

Table 10. Regression 3 Results[a]

Parameter	Variable	Point Estimate	Standard Error	t-statistic	P-Value (2 tails)
β_0	Intercept term	0.81470	0.16330	4.98911	0.00000
β_1	County mean real estate appreciation	0.35195	0.13270	2.65226	0.00888
β_2	Local traffic volume	– 0.15970	0.09995	– 1.59784	0.11224
β_3	1st access measure: number of turns	0.00840	0.01498	0.56055	0.57579
β_{31}	Bus. Type 1 × 1st access measure	0.01572	0.05250	0.29948	0.76500
β_{32}	Bus. Type 2 × 1st access measure	– 0.00345	0.04085	– 0.08447	0.93280
β_4	2nd access measure: travel distance	0.01709	0.01279	1.33616	0.18358
β_{41}	Bus. Type 1 × 2nd access measure	– 0.06017	0.04329	– 1.38980	0.16671
β_{42}	Bus. Type 2 × 2nd access measure	– 0.01450	0.05301	– 0.27345	0.78489
β_5	Occurrence of reconstruction dummy	– 0.01032	0.00638	– 1.61576	0.10830
β_{51}	Bus. Type 1 × reconstruction dummy	0.01307	0.01070	1.22152	0.22386
β_{52}	Bus. Type 2 × reconstruction dummy	– 0.01255	0.01168	– 1.07452	0.28436

Bus. = Business. [a] The model shown in Table 10 explained 14.09% of the variation in the change in assessed parcel values. The sum of squared residuals equaled 0.16292 with 146 degrees of freedom.

As in the Equation 1 regression, the statistical estimates of the parameters β_3, β_{31}, β_{32}, β_4, β_{41}, β_{42}, β_5, β_{51}, and β_{52} address the research question: the β_3s as a group measure the sensitivity of assessed property values to changes in the number of turns required; the β_4s as a group measure the sensitivity to the travel distance required; and the β_5s as a group measure the correlation between assessed values and the occurrence of VDOT reconstruction work. As the Methods section notes, Equations 1 and 3 are equally defensible *ad hoc* specifications of the relationship between the growth rate of assessed parcel value and the explanatory variables. No basis for judging between them exists except the empirical basis of ascertaining which equation better fits the data.

A comparison of Tables 10 and 4 reveals that the estimate of every parameter has the same sign in Equation 3 as it had in Equation 1. With the exception of the constant term, the values of the parameter estimates in Equation 3 are quite similar to those in Equation 1. The standard errors of the estimates, their t-statistics, and their P-values also change little.

The change in the size of the constant term is an artifact of the change in specification. To fit a set of average growth rates expressed as ratios (numbers slightly greater than or less than one) rather than as rates of increase (numbers slightly greater than or less than zero), the constant term has to be close to one rather than close to zero.

The parameters on the measures of access change in all cases have the same signs in Equation 3 as in Equation 1, and they are all statistically insignificant. The parameters for the dummy variable that indicates the presence or absence of reconstruction have the same signs in Equation 3 as in Equation 1. As was the case with Equation 1, the parameters on the reconstruction dummy imply that the growth rates of assessed value of commercial parcels occupied by a Type 2 or Type 3 business—the types expected to be less sensitive to changes in access—exhibit a small, statistically significant correlation with the occurrence of VDOT reconstruction work.

The difference between the models that Equations 1 and 3 represent is rather subtle. If one plots a graph of the growth rate versus one of the measures of change in access, holding other variables constant, one obtains from Equation 3 a straight line—each one-unit change in the access measure produces the same amount of change in the growth rate. Doing the same thing, one obtains a curved line from Equation 1—each one-unit change in the access measure produces a bigger change in the growth rate than the previous unit of change produced. No standard statistic, such as a t-statistic or F statistic, tests the null hypothesis that the two model specifications in Equations 1 and 3 fit the data equally well.

The investigators computed the values that the fitted model Equation 1 predicts for the dependent variable $\Delta\ln PV_i$ for each parcel i in the dataset. Next, they derived the values that these predicted values imply for the dependent variable ΔPV_i in Equation 3: $\exp(\Delta\ln PV_i) = \Delta PV_i$ for each parcel i. Last, they computed the residual, $R_i = \Delta PV_i$ (actual) – ΔPV_i (predicted by Equation 1), for each parcel and summed the squared residuals. This sum equaled 0.16260. They compared it with the sum of squared residuals for Equation 3, $R_i = \Delta PV_i$ (actual) – ΔPV_i (predicted by Equation 3). This sum, as Table 10 reports, equaled 0.16292.

The investigators similarly computed the values that the fitted model Equation 3 predicts for the dependent variable ΔPV_i for each parcel in the dataset. Next, they derived the values that these predicted values imply for the dependent variable $\Delta\ln PV_i$ in Equation 1: $\ln(\Delta PV_i) = \Delta\ln PV_i$ for each parcel i. Last, they computed the residual, $R_i = \Delta\ln PV_i$ (actual) – $\Delta\ln PV_i$ (predicted by Equation 3), for each parcel and summed these squared residuals. This sum equaled 0.15209. They compared it with the sum of squared residuals for Equation 1, $R_i = \Delta\ln PV_i$ (actual) – $\Delta\ln PV_i$ (predicted by Equation 1). This sum, as Table 4 reports, equaled 0.15171.

Regardless of whether the residuals are computed in Equation 1's or Equation 3's terms, the predictions of Equation 1 produce a slightly lower sum of squared residuals. This is evidence that Equation 1 fits the data set slightly better.

DISCUSSION

The findings reported previously invite comment that falls into five broad themes. The first is the strengths and weaknesses of the measure of business impact. The second is the effective sample size. The third is the strengths and weaknesses of the selected measures of access change. The fourth is the complexity of the relationship between VDOT reconstruction work and the value of commercial real estate. The fifth theme is directions for future research.

Use of Assessed Values Rather than Sales Data

The data the investigators collected for this study were reasonably well suited to address the questions of VDOT's Right-of-Way Division staff but somewhat less suited to address the questions of transportation planning staff. Assessed property values are one of the types of data with which Right-of-Way Division staff have to work. The limitations of assessment data reflect realistically the "fog of war" in which right-of-way negotiations take place. For planning staff, on the other hand, the questions they have encountered concern sales revenue. Assessed property values are a second best substitute for the sales data that would address the question precisely.

Sample Size

The sample of commercial parcels used in this study was considerably larger than would have been possible even a few years ago. Miller (2020) focused on RCUT data from other states in 2020 because RCUTs in Virginia were so new that virtually no "after" data were available. For the purposes of this study, the sample was fairly small. Nonetheless, for reasons outlined previously, the findings must be considered a first cut at a dataset that will continue to expand as the Commonwealth builds more innovative intersections. Further analysis of more data might alter some of the p-values and coefficients reported in Tables 4 through 10.

Not every innovative intersection design affects the access to every commercial parcel that adjoins the roadway where the intersection is constructed. In this study, the dataset was not as rich as the investigators initially imagined because even the parcels in the treatment group, which made up more than one-half of the sample, did not always experience a change in access by the access measures the investigators defined.

Among the 158 parcels for which usably complete data were retrieved, moreover, less than one-half, or 67, housed commercial establishments in one of the two business categories (Types 1 or 2) considered more likely to be affected by a change in access. Only about one-half of these parcels, 20 in Business Type 1 and 14 in Business Type 2, were treatment group parcels, which could have experienced a change in motorized access resulting from VDOT road work. According to the access measures the investigators defined, only five Type 1 and five Type 2 businesses experienced a measurable change in the number of turns required on one or more

approaches. Only thirteen Type 1 and nine Type 2 businesses experienced a measurable change in the travel distance required. In short, the set of observations available to estimate the parameters β_3, β_{31}, β_{32}, β_4, β_{41}, and β_{42}, which revealed sensitivity to measured changes in access, was actually quite small.

Selected Access Measures

The two access measures employed in this study were intuitively appealing and comparatively easy to read directly from plans or from aerial photographs. The measures offer a good likelihood of capturing the changes in motorized access that influence motorists, in the motorists' capacity as potential customers of a commercial establishment that fronts the road on which they are driving. However, other measures of motorized access are possible, two of which are noted here.

Turning Movements Required to Exit an Establishment

A VDOT project completed in 2012, listed as "Unknown_12" in the Supplemental Materials, involved reconstructing a section of median on Route 33 (East Market Street) in Harrisonburg. Before the reconstruction, a cut in the median allowed vehicles to make left turns from East Market Street into the parking lots of the businesses on either side of the street (a Cookout at 1688 East Market Street and a Chick-fil-A at 1691 East Market Street). The cut in the median also allowed vehicles leaving the parking lots to turn left onto East Market Street.

The VDOT work installed a concrete "island" in the middle of the median cut. After the reconstruction, this island created a physical barrier between the southbound cars, which were executing a left turn from East Market Street into the parking lot of the business on the east side of the road, and the northbound cars, which were executing a left turn from East Market Street into the parking lot of the business on the west side of the road. This island *prevented* cars leaving either parking lot from making a left turn onto East Market Street.

The access measures in this study are defined in terms of the movement required to *enter* a parking lot. They take no account of changes in the movement of vehicles *leaving* the parking lot. They therefore recognize no change in motorized access. If a change in access exiting the lot influences a motorist's decision to stop at either of the businesses on East Market Street, this study's methodology will fail to capture it.

Length of Time Required to Enter an Establishment

A VDOT project completed in 2017, project number 98244 in the Supplemental Materials, involved reconstructing the signalized intersection of Brewers Neck Boulevard and Benns Church Boulevard in Isle of Wight County. Before the reconstruction, northbound vehicles on Benns Church Boulevard were permitted to turn right (east) onto Brewers Neck Boulevard in a dedicated turn lane that branched off just before the intersection. After the reconstruction, the modified geometrics of the intersection, along with new signage and lane markings, prevented northbound vehicles from turning right at the intersection. Drivers on Benns Church Boulevard who wished to proceed east on Brewers Neck Boulevard must now turn right

further south onto Benn's Grant Boulevard, the newly constructed "quadrant" road, some 1,100 feet south of the traffic signal at the intersection of Benns Church Boulevard and Brewers Neck Boulevard.

A Citgo gas station at 19417 Brewers Neck Boulevard occupies the parcel on the northeast corner of the intersection. Vehicles can access the parking lot from the northbound lane of Benns Church Boulevard, just after they pass through the signalized intersection. Vehicles can also access the parking lot from the westbound lane of Brewers Neck Boulevard, just before they reach the intersection. Before the reconstruction, a motorist who intended to stop at the business on the northeast corner would proceed to the intersection. If the signal were green, the motorist would proceed through the intersection and turn right into the parking lot from Benns Church Boulevard. After the reconstruction, this movement remained possible. If the signal were red, however, and if the motorist were at the front of the queue approaching the red light, it is possible that the motorist might have attempted to save time—in exchange for more turns and greater distance—by turning right at the intersection and then approaching the Citgo parking lot from Brewers Neck Boulevard. After the reconstruction, a motorist forced to stop at the intersection by a red light no longer had the option of saving time by turning right onto Brewers Neck Boulevard. The motorist must wait for the signals to change and then proceed through the intersection.

The access measures in this study are defined in geometric terms: the number of turns required, the travel distance required, or the presence of a reconstruction. They take no account of travel time. In the example above, they identify the movement through the intersection and the right turn into the parking lot as the shortest turning movement: one turn, before and after; same distance, before and after. These access measures ignore the option of taking more turns if the signal is red. They therefore recognize no change in motorized access. Nonetheless, the prohibited right turn has a real impact, in a probabilistic sense, on the travel time cost of northbound motorists who wish to stop at the business on the northeast corner. If a change in the average wait time at the intersection influences a motorist's decision to stop at this business, this study's methodology will fail to capture it.

The Complexity of the Relationship between VDOT Work and Property Values

The changes in access that the study method measured exhibited generally positive, although statistically insignificant, correlations with the growth of real estate assessments. On the other hand, the study results suggest that some mechanism, which the study did not measure, is responsible for a small, possibly statistically significant relationship between the presence of VDOT reconstruction work and increases in real estate assessments. It is not possible to say what is causally prior to what in this relationship. However, it is possible to make some remarks about the other factors that might be involved.

First, the locations of the VDOT projects included in the sample used in this study reveal that road segment or intersection reconstruction is more frequent in counties and cities where population or economic activity, or both, are increasing. These socio-economic background factors, which affect the likelihood of a VDOT reconstruction project and the traffic volume, can also influence real estate values through channels other than road work or traffic volume.

Second, the fact that each of the real estate assessments studied in this report evolved in the context of a safety enhancement or a travel delay reduction is not incidental information. The interchanges or segments whose geometry VDOT redesigns generally are those where a problem has been identified. A history of crashes may have revealed a safety problem; traffic volumes may have revealed a current or upcoming congestion problem. Business establishments are certainly sensitive to crashes and congestion queues on the approaches to their parking lots. It cannot be assumed that the findings from a study such as this one would hold for a sample of commercial parcels whose motorized access was affected by construction that was *not* designed to address safety or capacity concerns—for example, right-of-way acquisition to extend an airport runway or to expand a port facility.

Directions for Future Study

This area offers several long-term research options. One option is to reuse the same study design used herein after the number of completed Virginia innovative intersections has been substantially expanded, such that multiple years of after-construction data can be obtained. A second option is to devise a research approach that allows the compilation of sales data from the businesses affected by a VDOT reconstruction project; such an approach would require the cooperation of businesses, as sales tax data are not publicly available in Virginia (Palmer, 2024). A third possibility is to use real estate sales data.

CONCLUSIONS

- *The statistical analysis indicated that the two measures of access change adopted in this study had no distinguishable negative impact on the assessed values of adjoining commercial real estate parcels within a window that extended four years beyond the completion date of the VDOT reconstruction work that caused the access change*. The access measure based on the number of turns had no significant impact. The point estimates of the impact tended to be weakly positive. The access measure based on the required distance traveled had no significant impact. The point estimates of the impact tended to be weakly positive.

- *The statistical analysis indicated the presence of a small, unexplained, possibly statistically significant, negative correlation between VDOT reconstruction work and the growth of the assessed values of adjoining commercial real estate parcels*. When the parcels were treated as a single group, this correlation was negative and significant at a p-value of about 2.5%. When the parcels were treated as three groups of different business types, this correlation was negative and significant only for the two business types expected to be less sensitive to access changes at p-values of about 4.1% and 6.4%, respectively. The regression results neither suggest a causal mechanism for this correlation nor indicate the direction the causation flows. They indicate only that the other variables in the regression failed to capture the link. Although the correlation could result from a mechanism by which VDOT work affects customer behavior, the correlation could also result from the presence of a third factor—population growth, economic activity, traffic congestion, or safety issues—that affects both VDOT reconstruction projects and commercial real estate assessments.

- *The statistical analysis suggested that many of the influences on the time path of a parcel's real estate assessment are highly location specific*. The explanatory variables used in the statistical analysis collectively accounted for 14.41% of the variance in assessed value growth among the 158 commercial parcels in the sample. In other words, a considerable portion of the variability in the growth of assessed real estate values appeared to depend on specific local factors other than those measured.

RECOMMENDATIONS

1. *VDOT Location and Design staff and Transportation Mobility Planning staff should incorporate the findings of this study into the materials about innovative intersections that they distribute to internal staff or to the public, as appropriate*.

2. *VDOT Right-of-Way Division staff should preserve, as a reference, a list of the treatment group and control group parcels, with identifying information pointing to the data included in the analysis*. On the occasion of a future project, when VDOT determines right-of-way acquisition is necessary, some parcels in the dataset may be usefully comparable with the parcels VDOT needs to acquire for that project.

IMPLEMENTATION AND BENEFITS

The researcher and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

Regarding Recommendation 1, within one year of this report's publication, VDOT's Location and Design Division will review the "long" (four-page) draft fact sheet shown as Appendix A and determine if it should be distributed to staff for internal use.

Also, regarding Recommendation 1, within one year of this report's publication, VDOT's Transportation Mobility Planning Division will review the "short" (one-page) draft fact sheet shown in Appendix B and determine if it is appropriate to incorporate into materials on innovative intersections for public distribution.

Regarding Recommendation 2, within one year of this report's publication, VDOT's Right-of-Way Division will review a table of identifying information for the parcels that have been studied in this report. This information is in the Supplemental Materials for this report and includes the VDOT project number, the county parcel number, the street address, and whether the parcel was in a treatment group or control group. The reason for this review is that if a future

planned highway reconstruction affects a commercial property similar to one of the parcels in the treatment group, then the information from the models (Equations 1 through 3) may help VDOT construct and substantiate their estimate of the potential impact, if any, on the market value of the affected property.

Benefits

The findings reported herein do not support a presumption that negative impacts on motorized access resulting from VDOT reconstruction will affect property value negatively. They indicate that the average impact of measured changes in access is negligible or weakly positive.

The findings in this report may have an effect in two areas of VDOT practice. First, better information about the business impacts of access changes may avert the tendency for questions about these effects to prolong the public involvement and the design approval processes during the PE phase. Second, a larger pool of relevant commercial information may enhance estimates of the cost of right-of-way acquisition, thereby improving budgeting efficiency. These two cost impacts are separate and additive.

A Shorter, and Therefore Cheaper, Preliminary Engineering Phase

First, these estimates of the impact of access changes on commercial enterprises provide answers to questions stakeholders have raised in online public input platforms and at public hearings when VDOT has presented an innovative design option. If these questions are answered quickly, then design selection and approval may proceed more quickly. As the literature review noted, expenditure in the PE category accounts for 11 to 18% of the cost of a typical VDOT reconstruction project, and the PE phase of the project delivery process may account for three-to-six months (13 to 26 weeks) of the total project delivery timeline. This report's Introduction section noted two VDOT projects in Pittsylvania and Gloucester Counties that were affected in recent years. The summary statistics of the projects in the dataset compiled for this study are based on a group of 48 reconstruction projects of the type of particular concern to this study. The number completed sufficiently long ago to be eligible for study amounted to 45, coming from 2009 to 2022, an average of three per year. This tally is almost certainly an undercount.

That said, the number of projects affected (the two in Pittsylvania and Gloucester Counties) and the number of projects "at risk" (48, counting the three too new to be analyzed) suggest that the risk is less than or equal to one in 24, that is, less than or equal to 4.167%. The summary statistics also show that the typical PE expenditure ranged from $2 million (the median) to $2.974 million (the average) per project. The big "unknown" is the quantitative impact of better answers to questions about changes in access on the length of the PE phase. If the availability of the findings from this study enabled VDOT staff to bring a project to advertisement in 25 instead of 26 weeks, and if the cost of PE were proportional to the length of the PE phase, then the cost savings might be estimated as 1/26 (3.85%) of $2 million, or $77,000 each time such questions arise regarding a project. Given the frequency with which such questions arise, this risk mitigation might apply to 4.167% of reconstruction projects that change access: $77,000 × 4.167% = $3,208.33 per project. In an average year, VDOT undertakes at least

three projects of this sort, probably more. The cost savings might therefore be on the order of $3,208.33 × 3 = $9,625 per year.

If the savings were expressed in terms of the total cost of a typical reconstruction project that changes access to a commercial parcel, once questions about lost profits due to access changes have already arisen, the avoidable PE cost might be expected to amount to at least 1/26 (3.846%) of the total PE expenditure, which historically has accounted for 11 to 18% of the total project cost: in other words, 1/26 x 11-to-18% = 0.42-to-0.69% of the total project cost. Such questions have been observed to arise in two cases out of 48, or 1/24 (4.167%). Before it is known whether questions about lost profits will arise, therefore, the average expected savings, among all projects that change access to a commercial parcel, might amount to 1/24 x 0.42-to-0.69% = 0.018-to-0.029% of the total project cost.

A Smaller, and Therefore Cheaper, Holding of Reserves for Right-of-Way Acquisition

Second, examples of commercial parcels subject to potential changes in motorized access in previous VDOT projects—parcels whose information was collected during this project—may enable the Right-of-Way Division staff to narrow the uncertainty of the cost estimate they use when they budget for a future real estate acquisition. The summary statistics compiled for this study indicate that the typical right-of-way expenditure ranged from $3.31 million (the median) to $8.65 million (the average) per project. As these expenses represent the acquisition of numerous parcels of real estate, most of which were not commercial, the median and average shed little light on the amount of money that might be at stake in negotiations with any one particular commercial landowner. Let us assume, purely for the sake of simplicity, that the acquisition cost is $500,000. The 20-80 low-high confidence range is very large, however, greater than a factor of two: $250,000 to $1,000,000. The "cushion" that must be factored into the cost estimate to cover the high-end contingency is correspondingly large, and the funds must be held in a demand account, paying low or no interest, until the project cost is known with greater certainty. *If* the parcel data compiled for this study allowed the low-high confidence range to be compressed from $250,000 to $1,000,000 down to $333,333 to $750,000, the required cost "cushion" would be reduced by $250,000, freeing up $250,000 to be held in a higher interest-bearing account or to be budgeted for another purpose, rather than be held in a low- or non-interest-bearing account for the duration of the right-of-way acquisition phase. If the time from funding to right-of-way acquisition were six months (26 weeks), then the foregone interest cost saved would be on the order of ½ year × 5% per year × $250,000 = $6,250 for one project. If these savings occurred on three projects per year, the total savings would be on the order of $18,750 per year.

The possession of more parcel records may conceivably shorten the right-of-way acquisition process in a manner similar to the way that possession of better answers to questions about the effect of access changes may shorten the length of the PE phase. Using the same numerical example as in the previous paragraph, if the right-of-way acquisition were completed one week faster, it would lead to a carrying cost savings of $^{1}/_{26}$ year × 5% per year × $750,000 = $1,442.31 for a single project. If these savings occurred on three projects per year, the total savings would be on the order of $4,326.93.

If these assumptions about the implications of the findings for the average length of design approval and the implications of the compiled database be realistic, then it would follow that a rough total benefit, again assuming three applicable VDOT projects per year, would be on the order of $9,625 + $18,750 + $4,326.93, or a bit more than $32,700, per year.

ACKNOWLEDGMENTS

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REFERENCES

Bared, J. *TechBrief: Restricted Crossing U-Turn Intersection*. FHWA-HRT-09-059. Federal Highway Administration, Washington, DC, 2009. https://www.fhwa.dot.gov/publications/research/safety/09059/09059.pdf. Accessed September 13, 2025.

Barnes, D.C., Jones, A.T., Lespier, L.P., Schuhmann, P., Vanajakumari, M., and Watson, E.D. *Economic Impact of SuperStreets*. FHWA/NC/2020-47. Cameron School of Business, University of North Carolina, Wilmington, NC, 2022. https://connect.ncdot.gov/projects/research/RNAProjDocs/RP2020-47%20Final%20Report.pdf. Accessed August 17, 2023.

Bass, T. Woods X-Roads RCUT Proposal Denied. *Gloucester-Mathews Gazette-Journal*, May 10, 2023. https://www.gazettejournal.net/woods-x-roads-rcut-proposal-denied/. Accessed July 19, 2023.

Carlton, B. Don't Use GPS to Travel Around Keysville Roundabout, VDOT Warns. *The Farmville Herald*, March 6, 2024. https://www.farmvilleherald.com/2024/03/dont-use-gps-to-travel-around-keysville-roundabout-vdot-warns/. Accessed March 6, 2024.

Federal Highway Administration. Restricted Crossing U-Turn Guided Tour, n.d. https://www.youtube.com/watch?v=nzpdTdXDfRw. Accessed April 17, 2026.

Fitzwater, J. VDOT: More Time Needed on Alternative. *The Gazette-Virginian*, March 6, 2024. https://www.yourgv.com/news/town_of_south_boston/vdot-more-time-needed-on-alternative/article_30d9a214-db2d-11ee-8189-d331e4bf2bb3.html. Accessed March 6, 2024.

Georgia Department of Transportation. *Economic Analysis of RCUT Access Impacts in Georgia*. Project GA RP 24-12. Atlanta, GA, initiated January 2025. https://trid.trb.org/View/2508954. Accessed July 2025.

Hodge, D. Economic Benefits of Complete Streets Investments in Massachusetts. In *Presentation at Concurrent Session 8, Pre- and Post-Project Analysis of Economic Development and Land Use Outcomes, at the Transportation Symposium on Environment, Energy, and Livable Economies*. Transportation Research Board, Denver, CO, August 28, 2024. https://trb.secure-platform.com/a/solicitations/161/sessiongallery/schedule/items/2182. Accessed August 18, 2025.

Huffman, C. A Left is NOT a Right: The Difficult Conversations of Access to Private Property. In *Presentation at Session 4, Confusion and Conflation in Access Management*, *at the Transportation Research Board 62nd Annual Workshop on Transportation Law*. Transportation Research Board, Richmond, VA, July 24, 2023. https://trb.secure-platform.com/a/solicitations/110/sessiongallery/1779/application/11076. Accessed April 14, 2026.

Hunziker, J. 'It's a Waste of Money:' Folks in Pittsylvania County Speak Out Against VDOT Proposal. *WSET News 13*, May 23, 2023. https://wset.com/amp/news/local/its-a-waste-of-money-folks-in-pittsylvania-county-speak-out-against-vdot-proposal-us-29-tightsqueeze-road-may-2023. Accessed July 19, 2023.

Kennedy, K.E. Top Factors Influencing Commercial Real Estate Value in 2024. *NAS Investment Solutions*, March 16, 2019. https://www.nasinvestmentsolutions.com/article/commercial-real-estate-value-factors. Accessed August 12, 2025.

Kilby, W.J. E-mail to J.S. Gillespie, August 5, 2025.

Kimley-Horn and Associates. *Before and After Innovative Intersections Study*. Transportation Mobility Planning Division, Virginia Department of Transportation, Richmond, VA, November 2024.

Lantz, Jr., K.E., Miller, J.S., and Beaton, J.S. *A Review of the Virginia Department of Transportation's Scoping Process and Options for Potential Improvements*. VTRC 08-R13. Virginia Transportation Research Council, Charlottesville, VA, 2008. https://vtrc.virginia.gov/media/vtrc/vtrc-pdf/vtrc-pdf/08-r13.pdf. Accessed January 14, 2026.

LegiScan. Virginia Senate Bill 666: An Act to Amend and Reenact §§ 25.1-100 and 25.1-230.1 of the Code of Virginia, Relating to Eminent Domain; Lost Profits, Approved April 27, 2022. https://legiscan.com/VA/text/SB666/id/2578418. Accessed August 16, 2023.

Liggan, J. E-mail to J.S. Gillespie, August 13, 2025.

Miller, J.S. *Impact of Innovative Intersections on Adjacent Parcel Values*. Project 115950. Virginia Transportation Research Council, Charlottesville, VA, May 2020. https://v92004.eos-intl.net/V92004/OPAC/Details/Record.aspx?BibCode=53273145.

Miller, J.S., and Turner, B.L. *Determinants of Variability in Preliminary Engineering Funding*. VCTIR 14-R2. Virginia Center for Transportation Innovation and Research, Charlottesville, VA, 2014. https://vtrc.virginia.gov/media/vtrc/vtrc-pdf/vtrc-pdf/14-R2.pdf. Accessed January 14, 2026.

Mirza, S. Town Council to Invite VDOT Representative Over Tightsqueeze Project. *Chatham Star-Tribune*, June 14, 2023. https://www.chathamstartribune.com/news/article_f20a99ca-0ac2-11ee-8989-937dc889aa3d.html. Accessed August 14, 2023.

North Carolina Department of Transportation. Reduced Conflict Intersections, May 2023. https://www.ncdot.gov/initiatives-policies/Transportation/safety-mobility/reduced-conflict-intersections/Pages/default.aspx. Accessed August 18, 2023.

Palmer, M. E-mail to J.S. Gillespie, June 12, 2024.

Plazak, D., and Preston, H. Long-Term Impacts of Access Management on Business and Land Development Along Minnesota 394. In *Proceedings of the 2005 Mid-Continent Transportation Research Symposium*. Iowa State University, Ames, IA, August 2005.

Schneider, H., Barnes, S., Pfetzer, E., and Hutchinson, C. *Economic Effect of Restricted Crossing U-Turn Intersections in Louisiana*. Final Report 617. Louisiana Transportation Research Center, Baton Rouge, LA, November 2019. https://www.ltrc.lsu.edu/pdf/2019/FR_617.pdf. Accessed August 16, 2023.

Trackbill. Virginia SB666: Eminent Domain; Redefines Lost Access and Lost Profits, 2022. https://trackbill.com/bill/virginia-senate-bill-666-eminent-domain-redefines-lost-access-and-lost-profits/2198445/. Accessed July 1, 2025.

Virginia Department of Taxation. Assessment Sales Ratio Studies, Richmond, VA, 2025. https://www.tax.virginia.gov/assessment-sales-ratio-studies. Accessed September 3, 2025.

Virginia Department of Transportation. IIM-LD-257: Innovative Intersections. Richmond, VA, 2018. https://www.vdot.virginia.gov/doing-business/technical-guidance-and-support/technical-guidance-documents/iim-ld-257-innovative-intersections/. Accessed April 14, 2026.

Virginia Department of Transportation. Innovative Intersections: Restricted Crossing U-Turn. Richmond, VA, 2023. https://www.vdot.virginia.gov/about/our-

system/highways/innovative-intersections/restricted-crossing-u-turn/. Accessed September 13, 2025.

Virginia Department of Transportation. Traffic Counts. Richmond, VA, 2025. https://www.vdot.virginia.gov/doing-business/technical-guidance-and-support/traffic-operations/traffic-counts/. Accessed September 12, 2025.

Wilborn, C. For Troubled Tightsqueeze Intersection Fix, VDOT Prepares New Plan After Public Outcry. *Danville Register & Bee*, July 29, 2023. https://godanriver.com/news/local/government-politics/for-troubled-tightsqueeze-intersection-fix-vdot-prepares-new-plan-after-public-outcry/article_78830cd6-2bb5-11ee-966c-2393b6729ed8.html. Accessed August 9, 2023.

APPENDIX A

"Long" Draft Fact Sheet: Business Impacts of Access Changes

Study Purpose

Construction projects such as median closures, the replacement of a traditional four-way intersection with a restricted crossing U-turn (RCUT), or left-turn prohibitions, change the maneuver some motorists must make to reach a parcel adjoining the roadway. Parcel owners and lessees, particularly those who operate a business, have expressed an interest in how these changes in motorized access affect the value of such parcels in Virginia. Accordingly, the study *Business Impacts of Access Changes (Study No. 124967)* examined how changes in access influence the assessed value of parcels used for business purposes from 2010 to 2023.

Changes in Access due to Reconstruction

The study examined 158 commercial parcels: a treatment group of 91 parcels adjoining 30 VDOT reconstruction projects, with completion dates ranging from 2009 to 2022 and a control group of 67 comparable parcels at nearby locations. Each of the VDOT projects entailed a possible change in motorized access for traffic coming *from* at least one approach direction *to* at least one adjoining commercial parcel (Figure A1).

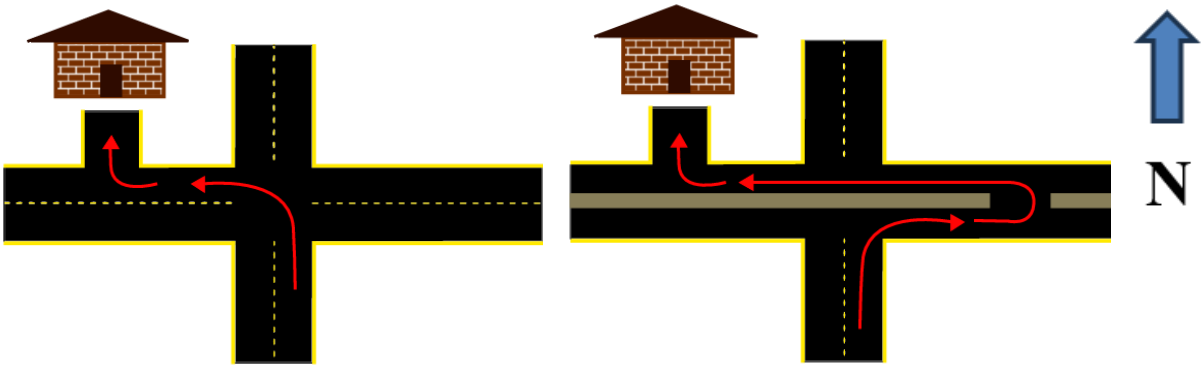

Figure A1. Example of Access Changes. (Left) Before reconstruction, northbound traffic requires 0.1 miles and two maneuvers—a left turn to the westbound route and then a right turn into the parking lot. (Right) After reconstruction, northbound traffic requires 0.3 miles and three maneuvers—a right turn to the eastbound route, a U-turn, and then a right turn into the parking lot.

How was a change in motorized access measured?

Each parcel's change in motorized accessibility, before and after the VDOT reconstruction, was quantified in two ways: (1) for each direction of approach, the change in the number of turning movements that a vehicle coming from that direction would have to make to access the parcel's parking lot and (2) for each direction of approach, the change in the distance that a vehicle coming from that direction would have to drive to access the parcel's parking lot. For a treatment group parcel, the changes might be zero or non-zero. For a control group parcel, the changes were zero.

For example, if VDOT constructed a median or closed the existing median at a certain location, left turns would no longer be possible at that spot. Motorists coming from an approach direction such that they formerly could have entered a commercial parcel's parking lot by making a *left* turn would subsequently have to pass the parcel, execute a U-turn, approach the parcel from the other direction, and enter the parking lot by making a *right* turn. The changes in motorized accessibility, described previously, would be reflected in both the number of turns and the distance traveled. Figure A1 shows an example where the construction of a median increases the number of turning maneuvers by one and increases the distance traveled by 0.2 miles.

How was the impact on a business measured?

Each treated parcel's change in assessed value from four years before the VDOT work to four years after the VDOT work was tabulated. The changes in the values of the control group parcels were tabulated for the same period as the VDOT project near them. The effect of any access changes was measured by the change in assessed value.

Each parcel was classified into one of three groups. The businesses deemed most dependent on spontaneous stop-in customer traffic, and therefore most likely to be affected by a change in motorized access, were assigned to Group 1 (gas stations, convenience stores, and fast-food establishments). The businesses deemed less likely to be affected were assigned to Group 2 (sit-down restaurants, hotels, grocery stores, pharmacies, and banks). The remaining businesses, deemed unlikely to be affected, were assigned to Group 3 (a broad range of establishments, including variety retailers, suppliers of automotive goods and services other than fuel, healthcare providers, education providers, and others). These group codes allowed the analysis to address the possibility that one group might be more sensitive to changes in motorized access than another group.

The inclusion of a control group of comparable parcels, each classified into one of the three groups, allowed the analysis to establish a baseline change in assessed real estate value against which the changes in the assessed values of the treatment group could be contrasted.

At each location, two background variables that were believed to influence the change in a parcel's assessed value were also tabulated. The first of these variables was the change in the estimated true value of all real estate in the county or city of the parcel location, from four years before construction to four years after construction. The second of these variables was the change in annual average daily traffic (AADT) on each road segment by which a motor vehicle might approach the parcel. These explanatory variables, it was hoped, would filter out local factors that might make a parcel in one location appreciate faster than a parcel in another county.

How did changes in motorized access affect business parcels in Virginia?

Three research questions emerged. First, did the assessed values of the parcels in the treatment group show a rate of change different from those of the parcels in the control group, once background influences such as the countywide average change in value and local changes in AADT were taken into account? Second, if a measurable difference did exist, was it associated

statistically with the measured changes in motorized accessibility? Third, was an effect detectable on the businesses in one group but not in another group?

These data showed four results.

- *Many of the influences on a parcel's real estate assessment appear to be location specific*. The explanatory variables used in the statistical analysis—that is, all the variables except for the change in real estate assessments—collectively explained 14% of the variance in the growth of assessed value on the sample of 158 commercial parcels. In other words, a considerable portion of the variability in the growth of assessed real estate values appears to depend on specific local factors beyond the measures of motorized access change, county-average real estate value change, and AADT change included in this analysis.
- The *change in the number of turning movements required to access a business parcel* was not associated with the change in the parcel's assessed value from four years before to four years after the access modification. In other words, as Figure A1 shows, if reconstruction of an intersection or a road segment meant that a motorist approaching from the east would have to execute a U-turn and a right turn to enter a business's parking lot, where previously the motorist would have had to execute a single left turn, this change was not reflected in the real estate assessment.
- The *change in the distance traveled to access a business parcel* was not associated with the change in the parcel's assessed value from four years before to four years after the access modification. In other words, if reconstruction of an intersection or a road segment meant that a motorist approaching from the east would have to drive 300 yards further to enter a business's parking lot than the distance the motorist previously would have had to drive, this change was not reflected in the real estate assessment.
- *Some evidence suggests a small, negative correlation between VDOT reconstruction work and the growth of assessed property value, via some relationship that the model employed in the study did not capture*. This correlation was positive and was not statistically significant for businesses believed to be the most sensitive to access, such as convenience stores or gas stations. This correlation was negative and was statistically significant for businesses not believed to be highly sensitive to changes in access, such as hotels or banks.

The complete Virginia study is available at https://vtrc.virginia.gov/reports/.

A recent study by Kimley-Horn, under a VDOT contract, produced some survey findings that flesh out the numerical findings of this study.

- *Most businesses reported either positive or neutral impacts on customer traffic after reconstruction*. One convenience store and two hotels reported a negative impact on customer traffic.

How did changes in motorized access affect business parcels in other states?

A few other states that have begun rebuilding intersections using non-traditional designs have also studied the effects of changes in motorized access on the adjoining businesses.

- A Minnesota study examined businesses before and after the reconstruction of an at-grade, free-access arterial (Trunk Highway 12 / U.S. Highway 12) as a limited-access freeway (Interstate 394). The effect on access to businesses fronting the road was similar to that on access to some of the businesses fronting an innovative intersection. The study period, 1984 to 2004, extended ten years beyond the completion of the road work in 1993. The statistical indicators of business health that the investigators studied—the number of businesses, turnover rate on a given parcel, gross retail sales, employment, and commercial land values—generally showed growth at or above the average for the metropolitan area and the state as a whole. The study, by David J. Plazak and Howard Preston (2005), is titled *Long-Term Impacts of Access Management on Business and Land Development Along Minnesota 394*.
- A Louisiana study examined before-construction and after-construction sales tax receipts at the intersection level to compare the average customer traffic before and after the construction of one particular type of access change: an RCUT. The investigators studied ten intersections in four study locations in Louisiana. They found no decrease in taxable sales between the two-year period before the improvements and the two-year period after but rather a slight overall increase. The study, by Helmut Schneider, Stephen Barnes, Emily Pfetzer, and Corey Hutchinson (2019), is titled *Economic Effect of Restricted Crossing U-Turn Intersections in Louisiana* and a summary is available here.
- A North Carolina study also looked at the economic impact of one type of access change: conversion from a signalized intersection to an RCUT intersection. For the portion of the study that focused on business parcels, the investigators obtained data from four intersections adjoining commercial parcels and from two intersections adjoining industrial parcels. A survey of the neighboring businesses showed that commercial properties that received many late-afternoon customers expected the most positive impact, and industrial properties expected the most negative impact. The study, by Donald C. Barnes, Adam T. Jones, Lizzette Pérez Lespier, Peter Schuhmann, Manoj Vanajakumari, and Ethan D. Watson (2022), is titled *Economic Impact of Superstreets*.
- A Georgia study is underway that will examine "any associated changes to economic performance of the impacted businesses nearby" RCUTs. The study, managed by Sabbir Ahmed and conducted by Yichang Tsai, is titled *Economic Analysis of RCUT Access Impacts in Georgia* and is expected to be completed in October 2026.

APPENDIX B

"Short" Draft Fact Sheet: Business Impacts of Access Changes

Study Purpose

Median closures, left-turn prohibitions, and restricted crossing U-turns (RCUTs) change how some motorists access nearby parcels. Virginia businesses expressed interest in how these travel changes affect the value of these parcels. The study *Business Impacts of Access Changes (Study No. 124967)* examined how access changes affected the assessed value of business parcels.

Changes in Access due to Reconstruction

The study examined 158 commercial parcels: a treatment group of 91 parcels adjoining 30 VDOT reconstruction projects, with completion dates ranging from 2009 to 2022, and a control group of 67 comparable parcels at nearby locations. Each project changed motorized access, such as a median closure, for traffic coming *from* at least one direction *to* at least one parcel.

Study Findings

- Neither a change in the *number of turning movements* nor a change in the *travel distance* required to access a business parcel showed an association with a change in the parcel's assessed value from four years before to four years after the access modification.
- *Much of the variability in the change in assessed real estate values appears to depend on specific local factors* besides changes in turning movements or travel distance, county average real estate value changes, and average annual daily traffic changes.

Other Published Findings

- A separate Virginia study surveyed businesses at ten locations where VDOT built an innovative intersection. After reconstruction, seven businesses reported positive or neutral impacts on customer traffic, and three businesses reported negative impacts on traffic.
- A Louisiana study examined before-construction and after-construction sales tax receipts at the intersection level to compare the average customer traffic before and after the construction of an RCUT, focusing on ten intersections across four study locations. No decrease was evident in taxable sales between the two-year period before the improvements and the two-year period after but rather a slight overall increase.
- A North Carolina study examined conversion from signalized intersections to RCUT intersections. For business parcels, the investigators obtained data from four intersections adjoining commercial parcels and from two intersections adjoining industrial parcels. A survey of the neighboring businesses showed that commercial properties that received many late-afternoon customers expected the most positive impact, and industrial properties expected the most negative impact.