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Accessibility in practice

A guide for transportation and land use decision making

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Credits

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Definition of terms

Because accessibility has only recently been employed in decision making, the practice lacks standardized nomenclature. One of the goals of this report is to begin to define important terms. The list below is derived from practice as developed since 2014 as part of Virginia's work to operationalize accessibility as a metric for selecting transportation projects.

Accessibility: The ease with which people may reach opportunities such as jobs, stores, parks, schools, and other destinations. "Ease" is measured in terms of travel time, with some adjustments to account for how travelers use the system.

> **Employment accessibility:** The ease (measured in travel time) with which travelers can access jobs from home locations.
>
> **Non-work accessibility:** The ease (measured in travel time) with which travelers can access stores, parks, schools and other common destinations from a given starting point.

Cumulative opportunities: A method of computing accessibility by summing the number of destinations that a traveler can reach.

Decay curve: A function used in computing accessibility that reflects people's willingness to travel in relation to travel time.

> **Decay-weighted destinations:** A unit of measure in a cumulative opportunities approach, where destinations count for less the longer they take to reach.

General Transit Feed Specification (GTFS): A widely used format for transit schedules and routes.

Network: A GIS representation of the four modal means of travel—walk, bike, transit, and auto. Networks are broken into segments that represent not only their place on the map but also particular attributes, such as auto speeds or pedestrian levels of stress.

Impedance: A factor used to impose travel-time "penalties" on networks where conditions would slow (e.g., hills for cyclists) or discourage (e.g., unsignalized crossings for pedestrians) travelers.

Point of interest (POIs): A place that would be useful for travelers to access. POIs can include schools, stores, parks, restaurants, and job sites–either by themselves or in combination.

Travel time: The time required to reach destinations via modal networks. Travel time may be actual (e.g., computed by automobile using observed travel speeds) or calculated with particular impedances (e.g., time penalties for poor walking conditions that would discourage use on a link).

Introduction

This report focuses mainly on ways to improve decisions about the built environment. It does so by describing improved methods and standards around access to destinations.

The decisions at issue here involve both transportation and land use—primarily what facilities to build (or not build) and where to locate them; but also how to design, maintain, and operate facilities. Specifically, this report provides ways to use the concept of accessibility to guide or inform these decisions in cities, towns, and metropolitan areas.

Accessibility is not a new concept in professional and academic literature. In 1973, for example, Martin Wachs and T. Gordon Kumagai defined accessibility just as we do today—"the ease with which citizens may reach a variety of opportunities for employment and services" —and called for the use of accessibility as a metropolitan "indicator," aka performance measure:

> Accessibility is perhaps the most important concept in defining and explaining regional form and function. In large part, the accessibility of a site to economic and social activity centers determines its value, the economic and social uses to which it will be put, and the intensity of development which will take place on it. Through accessibility, there is a systematic relationship between the spatial distribution and intensity of development, and the quantity and quality of travel within a region. The influence of accessibility upon city form is well known, and can be exemplified through the study of changes in urban development patterns which occurred when cities experienced a series of changes in accessibility patterns as horse cars, trolley cars, suburban railroads, rapid transit lines, and the automobile each became available.[1]

Until recently, however, limitations on data, computing power, and methods for calculating accessibility meant that the concept was mostly relegated to academia or one-off studies. Now, as we surmount those limitations, there is an explosion of interest in accessibility and its power to improve real-world decisions. See for example, some good discussions about accessibility in these new resources:

- "The Why and How of Measuring Access to Opportunity: A Guide to Performance Management" (Governor's Institute of Community Design, 2017, available at https://smartgrowthamerica.org/resources/measuring-access-to-opportunity/).
- "Moving to Access" (Brookings Institution, undated, available at https://www.brookings.edu/project/moving-to-access/).
- "Access Across America" (University of Minnesota Accessibility Observatory, undated, available at http://ao.umn.edu/research/america/).

This report adds a critical element to the growing literature on accessibility by 1) demonstrating ways to use accessibility to improve decisions about particular projects or programs (sets of projects), and 2) attempting to provide a common vocabulary around the use of accessibility. It is largely informed by work done to operationalize accessibility measures for the Virginia Department of Transportation. As such it provides somewhat more guidance on transportation decision making. But VDOT’s work was intended to improve land use outcomes as well, and this report addresses those decisions too.

Background and rationale

Transportation and land use decisions are informed by a host of measures and standards of practice. Land developers locate, design, and finance their projects based on market studies, pro formas, and other tools. DOTs design highways in accordance with guidance from AASHTO and other design standards. Planners recommend transit expansions based on travel demand model outputs. Zoning administrators approve projects based on permitted land uses, required setbacks, and limits on massing. These measures and standards evolve over time, along with policy and economic conditions and innovations in practice that provide better guidance. Think of the medical profession as an analog: A century ago physicians treated broken bones and tendons based on a patient's description of the pain or obvious anomalies in the skin. Later they improved their ability to diagnose and treat such problems by using X-rays. And today they have even more accurate and precise guidance from 3-D MRI scans. In some ways, despite a myriad of standards, land use and transportation decision making is at a stage well before 3-D MRIs.

Yet greater data availability and analytical capacity today provide new opportunities for improvement. Accessibility is not the be-all and end-all measure of the built environment, but it does offer some important advances:

- It measures what travelers care about—how readily they can meet their needs. It takes into account vehicle speed but also distance of trips, and so can be superior to conventional vehicle-speed measures in guiding decisions.
- It provides a common platform for considering land use and transportation questions. Both transportation networks and land uses can be manipulated, e.g., during scenario planning, to evaluate accessibility outcomes.
- It provides a common measure for assessing various transportation modes. Accessibility measures how many opportunities travelers can reach, or how long it takes travelers to reach opportunities, and this metric—unlike various level-of-service measures—is consistent across modes.
- It is nearly infinitely scalable, from individual points up to regions and states. Small transportation projects are invisible in most demand models, so accessibility can help fill that gap and remove a bias toward big projects.
- It can be calibrated to represent a variety of network or land use conditions. For example, auto accessibility can be pegged to observed travel speeds at various times of day and walking accessibility can be adjusted for level-of-stress, while fine-grained POI data allow drawing important distinctions, e.g., between convenience stores and grocery stores when considering food deserts.
- It requires relatively little training. The accessibility analysis described in this report is conducted in ArcGIS with an add-on tool that employs user-friendly drop-down menus.
- It is understandable for non-technical stakeholders. Where many models rely on numerous assumptions and complex calculations, accessibility describes travel times.
- It is relatively quick to calculate. As such, it can be used to generate multiple scenarios in a short time.
- It can be used to predict outcomes. While accessibility analysis does not replace predictive models, by comparing modal accessibilities we can estimate outcomes such as vehicle-miles traveled, mode share, personal transportation costs, and emissions.

- It can provide a critical link between policy goals and decision making in practice. Accessibility can be assessed at key decision-points—approval of a land-use project, design of a highway, development of an area or corridor plan—to determine those decisions' impacts on policy goals.

In other words, accessibility measures can be used to:
- scan for current conditions,
- track conditions over time as performance measures,
- scan for problems,
- assess various potential solutions, and
- communicate all of this to non-technical decision makers.

Potential specific-use cases are many, but consider this example: A city sets policy goals for managing traffic and improving the economy. With conventional measures and practices, those broad goals would be hard to put into effect in individual decisions around transportation and land use. However, we know that where walking-scale accessibility to everyday destinations is higher, VMT is usually lower (Figure 1) and property values usually higher (Figure 2). So we can assess transportation plans and projects on whether or not they provide such walking access, or land use plans and projects on whether they provide accessibility between residential and non-residential uses.

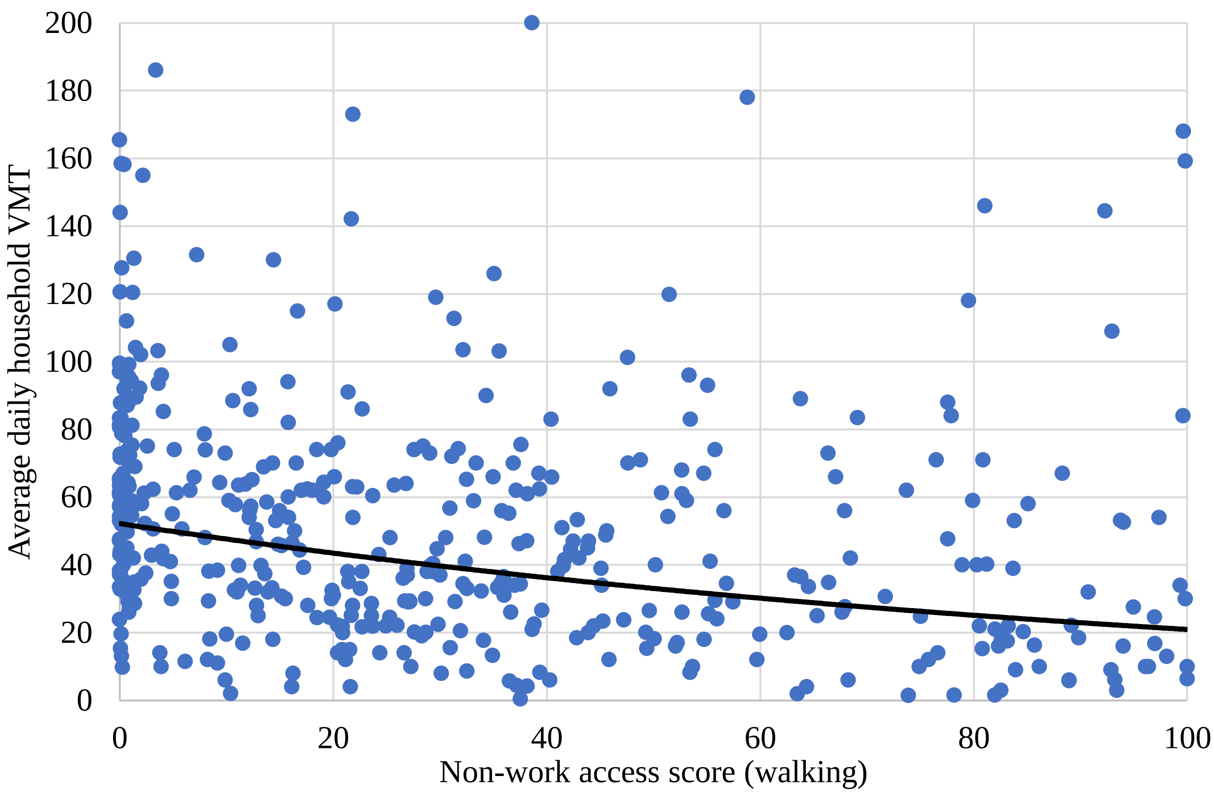

Figure 1. Non-work access versus average daily household VMT for Census block groups in a four-region sample of Virginia (data source: Sugar Access and NHTS 2009)

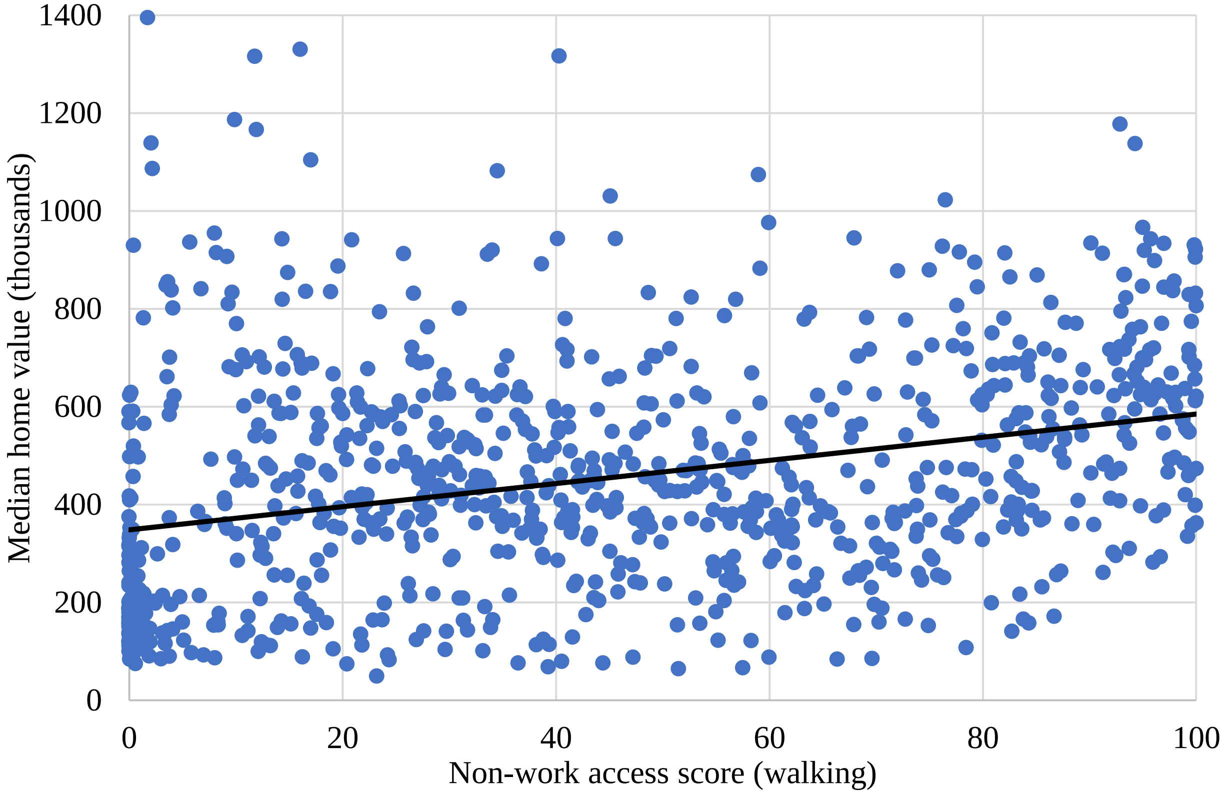

Figure 2. Non-work access versus median home values for Census block groups in a four-region sample of Virginia (data source: Sugar Access and U.S. Census ACS 2011-2015)

While accessibility is a relatively straightforward concept, there is more to it than simply calculating a number. To be really effective in shaping outcomes, accessibility needs to be measurable and applicable *at the project level.* In other words, it needs to address common real-world questions, such as: Will improving bus headways or changing bus routes significantly improve accessibility (and thus ridership)? What level of neighborhood retail should be required in a new subdivision? Does Highway Project A or Transit Project B afford more accessibility to jobs per dollar of investment? How can an operational change or maintenance project improve accessibility along a corridor? What first- and last-mile impediments are limiting transit accessibility?

In Virginia, a 2014 statute created Smart Scale, a system to prioritize transportation projects on several objective criteria, including accessibility and land use. As a result, the Commonwealth's Department of Transportation, Office of Intermodal Planning and Investment, and their consultants and stakeholders have operationalized project-level accessibility. Two rounds of projects have been scored under Smart Scale, with a score for multimodal accessibility to employment. At this writing, a measure for non-employment accessibility has been developed but not yet adopted as part of Smart Scale. At the same time, the Commonwealth is making accessibility software and data available to the state, local, and metropolitan governments so that they can propose higher-scoring projects and employ accessibility measures for their own transportation and land use decision making. That software is Citilabs' Sugar Access.

This guide is not intended as a tutorial on Sugar or the ArcGIS platform on which it relies. And while it refers to measures developed for Smart Scale, it is not a manual for prioritizing Virginia transportation projects. Rather, it provides a guide for using accessibility in land use and transportation decision making more generally, informed by work conducted for Smart Scale.

It should be noted that while the rationale for considering accessibility is strong, accessibility does not answer every question. For example, while it lets us know what opportunities people could access, it doesn't tell us what places they actually go. (Virginia has done some work in considering this issue—the origins, destinations, routes, and other attributes of people's trip making—in a separate project. See: http://www.ssti.us/Events/big-data-trip-making-and-tdm-in-northern-virginia/). Likewise, while accessibility is a powerful concept in understanding personal travel, it has less relevance—at least until new methods develop—in guiding decisions around freight. Questions of aesthetics, certain environmental impacts (such as stormwater runoff), urban design issues of building setbacks and massing, and many others are not relevant to accessibility as currently operationalized. And while the use of accessibility to predict outcomes is promising, this work needs more development and is unlikely to completely replace, for example, transportation demand models.

The rest of this report 1) describes basic data, methodology, and other issues involved in calculating accessibility, 2) demonstrates how to assess accessibility for transportation projects, 3) demonstrates how to assess accessibility for land use projects, and 4) describes how to use accessibility to predict certain outcomes.

Accessibility basics

We define accessibility in the same way Wachs and Kumagai did in 1973—"the ease with which citizens may reach a variety of opportunities for employment and services."[2] The concept of "ease" could be operationalized in terms of time or dollar costs, or perhaps a combination, or in other ways. Because we have much more information about travel time —both in terms of available data from which to make calculations and in terms of what we can observe about travel behavior effects[3]—in this guide we operationalize accessibility mostly in terms of time. So we could nearly substitute "time by which" for "ease with which" in the definition. Where we depart from plain travel time is with active transportation modes, where "level-of-stress" is important in whether a facility truly provides access to users.[4] Going forward, it would also be desirable to distinguish between waiting time and in-vehicle travel time for transit users, counting a minute of the former as more than a minute of the latter; this and other such improvements would be fairly straightforward to operationalize in the framework described in this report.

Since we want to allow for time "penalties" or "bonuses" —which we describe later in the "impedances" section—our definition of accessibility is this:

Accessibility is defined as the ease with which people may reach opportunities such as jobs, stores, parks, schools, and other destinations. "Ease" is measured in terms of travel time, with some adjustments to account for how travelers use the system.

Three elements

Assessing accessibility requires three things: 1) Maps or GIS files of modal **networks**, which depict where and at what speeds travelers can use the system; 2) locations of land uses, including households and **points of interest (POIs)** —jobs, stores, etc. —that people visit; and 3) a system to calculate travel times between POIs or from homes or other starting points to POIs. It is possible to load these data—many are readily available, while others are more difficult but possible to acquire—into a GIS database and use a tool such as the ArcGIS Network Analyst to calculate travel times. As previously noted, the Virginia team has opted to use an ArcGIS add-on tool called Sugar Access, which provides basic data and simplifies the process for calculating accessibility.[5] The following section describes the three elements listed above in the context of using Sugar Access. Concepts would be similar if the user chooses a different tool.

Networks

Modal networks need to depict the spatial extent and certain attributes of streets, bus routes, bike paths, sidewalks, and other facilities for all four personal transportation modes. In GIS and Sugar Access, these networks are represented as a series of interconnected links. For analysis of changes to the networks, links can be added to represent new facilities, links can be removed to represent facilities no longer in service, and attributes of links (such as auto travel speed) can be changed. In general, we want to be able to reflect the accessibility effect on a wide variety of transportation-system changes, so we want a robust collection of attributes with our links. As one might expect, given the resources devoted to each of the four modes, auto networks today are most robust in terms of attributes, followed by transit and active transportation modes:

- ***Auto.*** With the proliferation of GPS navigation systems and resulting data, auto networks are robust and can be obtained from various agencies and vendors. The auto network in

Sugar Access provides travel times for links by time of day, as obtained from probe vehicles.

- ***Transit.*** Thanks to Google Maps, most large transit agencies report their schedules in a format called the General Transit Feed Specification, originally the Google Transit Feed Specification, or GTFS. Sugar Access employs GTFS data, as well as scheduled transit service from smaller transit agencies that are manually added. Because first- and last-mile travel times to and from transit stops are critical elements that affect the ability to travel on transit, these should be included in transit travel times. Be default, Sugar Access uses walk times as first- and last-mile connections. In some cases it might be desirable to use auto travel times, e.g., to and from transit station parking lots. Note that while auto travel times are based on observed probe vehicle times, GTFS-based transit travel times are based on schedules, and hence somewhat less robust (though it would be feasible to replace the scheduled times with observed times where these data exist).
- ***Bicycle.*** Valid and consistent network data on bicycle networks are harder to obtain than those for auto and transit. Spatial network data showing where cyclists can travel—on non-freeway auto facilities plus bicycle or multiuse trails—is available and incorporated in Sugar Access. However, detailed attributes of network links are harder to come by; it's as if we had transit routes without schedules. One day, actual speed and route data from cyclist travel will be available, but until then the Virginia accessibility team is exploring ways to approximate desired attributes, such as level-of-stress from traffic and speed effects from hills, by assigning impedances to certain links, as described below.
- ***Walk.*** Similar to bicycle networks, available walk networks can do a good job showing where people can walk, even including details that show sidewalks on both sides of a street (if they exist) rather than attaching them to a centerline, so that crossings can be considered. As with bicycle mode, we would like to represent the "ease" of accessing destinations by incorporating level-of-stress and potentially other considerations. Again, the Virginia team has done this by attaching impedances to links in certain situations.

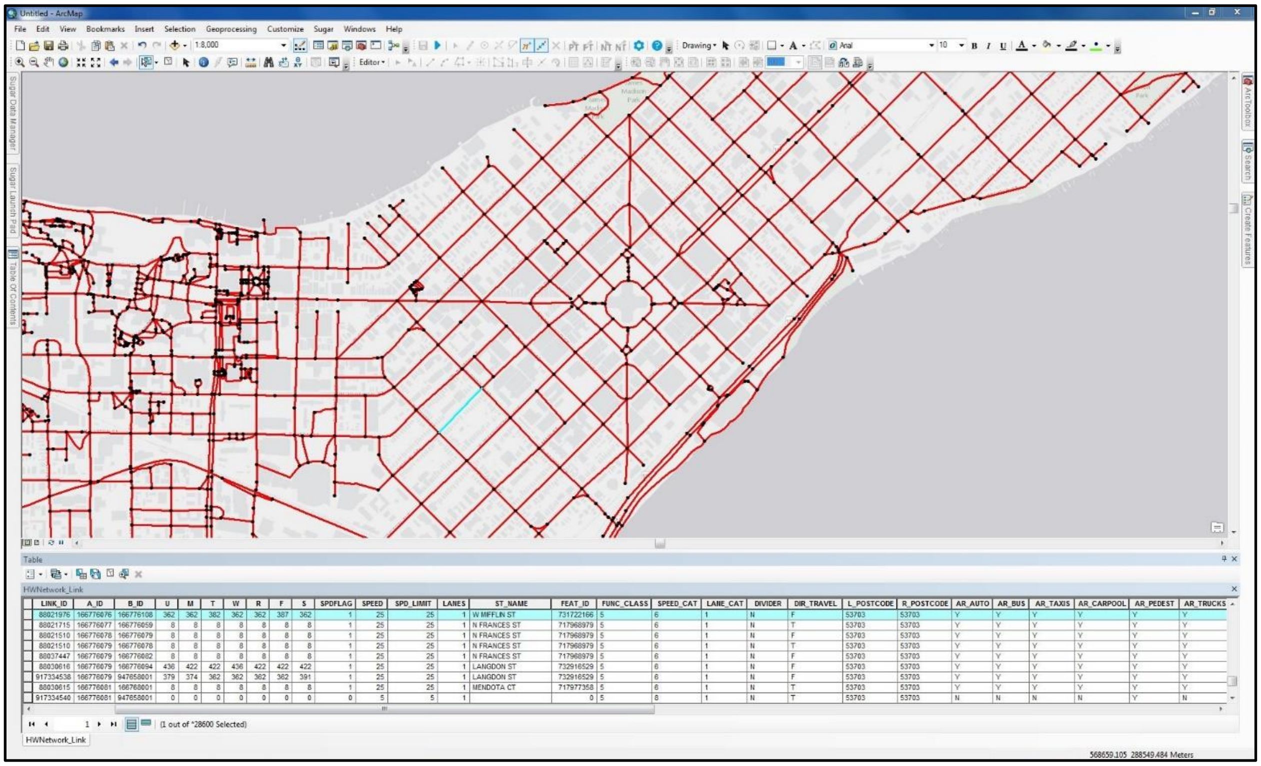

Figure 3. Auto, bicycle and walking networks with attribute table as they appear in ArcMap with Sugar Access add-on.

Land uses

Because of concern about peak-hour travel congestion, as well as the economic benefit of being able to access employment, often accessibility is described in terms of access to jobs. But most trips are non-work trips, so we want to take account of these sorts of destinations as well. Various vendors and agencies can provide points of interest (POI) data. In Sugar Access, location of jobs comes from the Census Bureau's Longitudinal Employer-Household Dynamics program, household locations from the decennial Census, and non-work POIs from the vendor that provides roadway networks and speeds, again originally driven by the need for these data in GPS navigation systems. If desired, default data can be replaced with, for example, more current or projected household data; Virginia's Smart Scale employs projected data for both households and employment. Unlike the system employed in Virginia, some other representations of accessibility omit land uses, simply displaying the footprint of the region a person could reach in a given time (aka travel shed). While such a visualization can be useful, to quantify accessibility in a way that is relevant to people's travel behavior, we need to distinguish between areas with POIs and other land uses and those with fewer or no land uses.

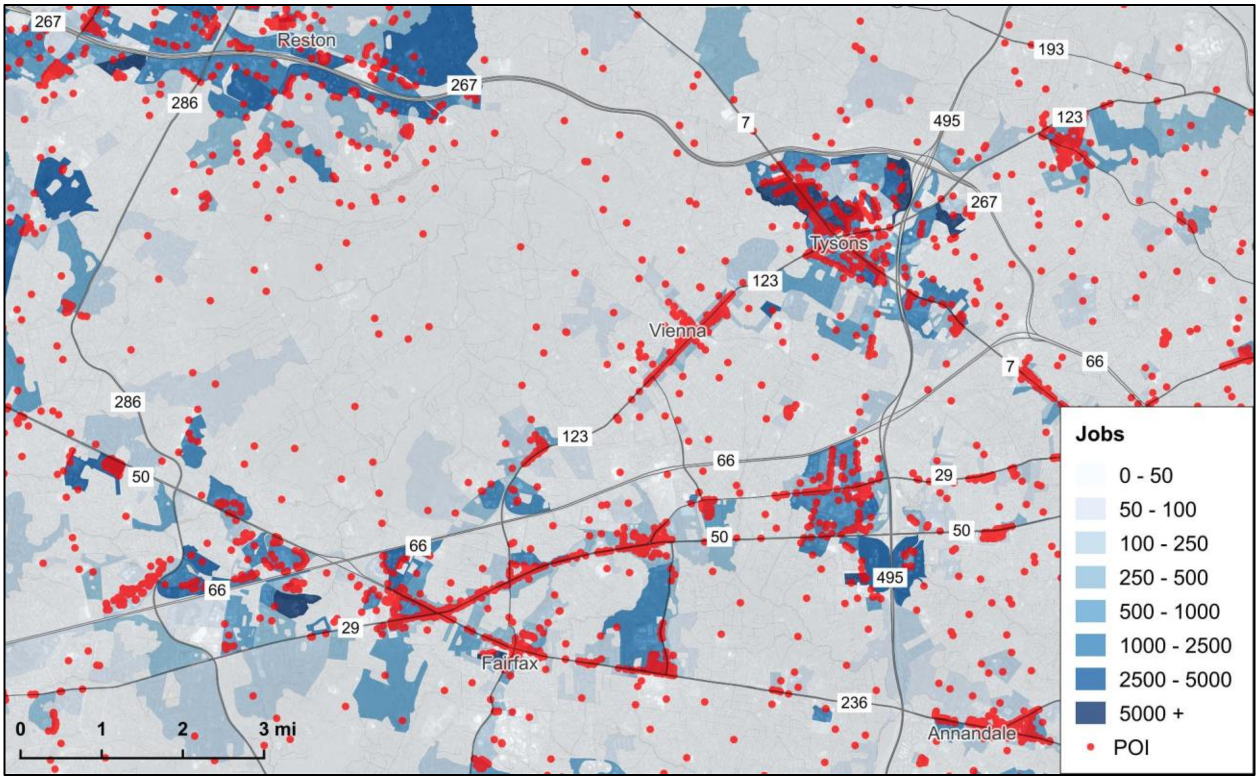

Figure 4. Jobs and non-employment points of interest for an area of Northern Virginia, included with Sugar Access.

In addition, sometimes we want to consider access to particular POIs or job types, rather than all. The Sugar tool breaks these into various categories. For example, job types from the tool are shown in Table 1.

Table 1. Employment types, defined in Sugar Access data.

Sugar Field	Jobs Definition	NAICS Sector
AGRI_FISH	Agriculture	Agriculture, Forestry, Fishing and Hunting (11)
MINING	Mining	Mining, Quarrying, and Oil and Gas Extraction (21)
UTILITY	Utility	Utilities (22)
CONSTRUCT	Construction	Construction (23)
MANUFACTURE	Manufacturing	Manufacturing (31-33)
WHOLESALE	Wholesale Trade	Wholesale Trade (42)
RETAIL	Retail Trade	Retail Trade (44-45)
TRANSPORT	Transportation	Transportation and Warehousing (48-49)
INFORMATION	Information	Information (51)
FINA_INSU	Finance/Insurance	Finance and Insurance (52)
REESTATE	Real Estate	Real Estate and Rental and Leasing (53)
PROF_SERV	Professional Services	Professional, Scientific, and Technical Services (54)
MGMT	Management	Management of Companies and Enterprises (55)
ADMI_WAST	Administrative	Administrative and Support and Waste Management and Remediation Services (56)
EDUCATION	Education	Educational Services (61)
HEALTH	Healthcare	Health Care and Social Assistance (62)
ARTS_REC	Arts, Entertainment	Arts, Entertainment, and Recreation (71)
ACCOMODATION	Hospitality	Accommodation and Food Services (72)
OTHR_SERV	Other Services	Other Services (81)
PUBLIC_	Public Administration	Public Administration (92)

Method for calculating travel times

As previously noted, travel times could be calculated with ArcGIS Network Analyst, but to do this efficiently for an entire study area would require some automation and significant computing power. It is also possible to calculate travel times using “skims” from travel-demand models, but these would be even more cumbersome and in most cases would not provide accurate results for short trips, due to the size of transportation analysis zones in the models. In Virginia, where several hundred projects must be scored in a matter of a few weeks, the team opted for a dedicated accessibility tool, Sugar Access, which is run from inputs in ArcGIS and does its computation in the cloud.

Regardless of the tool, an important issue to consider when calculating accessibility is that if we allow for infinitely long trips, every place is accessible to every other place. Clearly this would be no help for decision makers. Some representations of accessibility use a hard boundary for what is considered accessible and what is not. For example, a map using such a construct might depict the area people starting at a particular place could reach within 45 minutes, and the analyst might sum the jobs or other POIs in that area to come up with an accessibility score. However, this method includes a 45-minute trip to a POI but discards a 46-minute one, and it equates a 45-minute trip with a 5-minute trip. In reality, travel time is a cost to the traveler and, all other things being equal, shorter trips are more valuable and impose fewer costs than longer trips. And this relationship is not well-represented by a hard cutoff, but rather by a sloping “decay curve” representing the declining utility as travel time increases. Using a decay curve to calculate accessibility, a POI that takes a long time to reach “counts” for less than a similar one that can be reached more quickly.

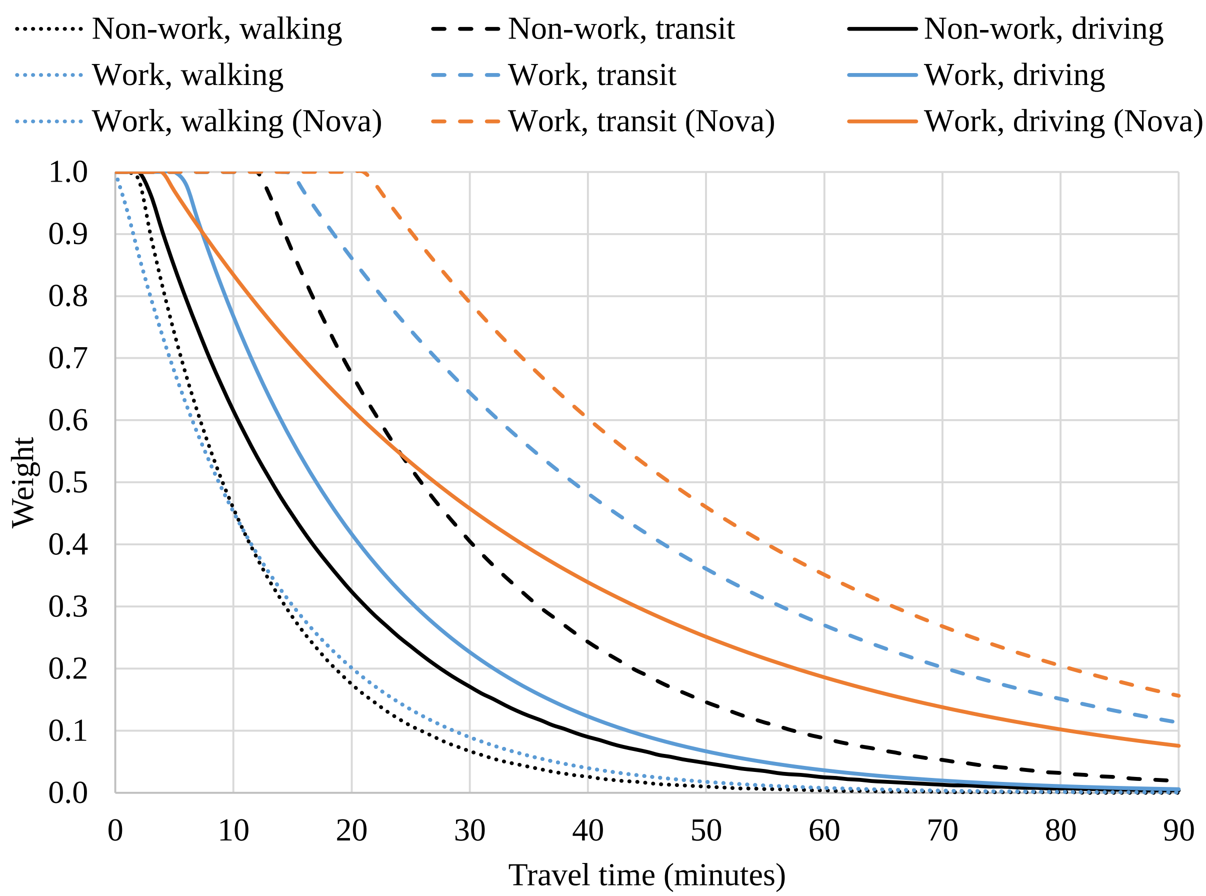

Figure 5. Travel-time decay curves by trip purpose, mode and region, derived from trips represented in the 2009 NHTS for Virginia.

Data to inform the slope and shape of decay curves comes from various travel surveys done at the national, state, and regional levels. After examining these data, the Virginia team has developed decay curves that vary by trip purpose (work and non-work), mode and location—observed journey-to-work times being longer in the Northern Virginia region than elsewhere. Constructing a decay curve is straightforward, as it is simply the smoothed cumulative distribution of observed travel times. Such a curve allows the utility of trips to naturally decay to zero, requiring no arbitrary cutoff, and when employed in analysis it can show the true benefit or cost of transportation or land use changes.

Impedances

Because we want an accessibility score that is sensitive to improvements (or decreases) to accessibility from changes to the built environment, we want to be able to take into account as many variables that relate to the "ease" by which people can travel; so that when they change, so does the accessibility measure. For example, an improvement in transit headways reduces travel times and improves accessibility. The same goes for a highway project that reduces delay, a new pedestrian overpass that improves connectivity, or a new grocery store in a food desert.

"Impedances" are network attributes that hamper accessibility, or reduce the ease with which people can reach opportunities. Impedances related to actual travel time, like those listed above—frequency of transit vehicles, location of stores, etc. —are so baked into the calculation of accessibility that we don't think of them that way, or need to. However, in some cases we can make accessibility much more useful by being intentional about impedances. For example, we might need to consider impedances for walking and biking that reflect unsafe or unpleasant conditions, such as being near fast or high-volume traffic. For the calculation of accessibility in Virginia's project prioritization process, impedances were developed based on factors outlined in the following table.

Table 2. Summary of walking impedances considered in Virginia's Smart Scale.

Factor	**Walk impedance**	
	Lowest	Highest
Functional classification	Local	Major arterial
Vehicle speed	<= 25 mph	> 40 mph
Number of lanes	<= 2	> 4
Sidewalk	Yes	No

Facilities with low impedances are assigned standard walking speeds, but those speeds are decreased by as much as 50 percent for facilities with high impedances. Certain facilities, such as major arterials with lower speeds and fewer travel lanes, are assigned medium impedances.

After continued discussion with others working on this question, and after considering more types of projects, this approach is being amended because in some cases it does not adequately penalize poor conditions (and conversely does not show enough benefit from mitigating these conditions). For example, a 40-foot, unsignalized crosswalk at a channelized right turn lane with significant auto traffic could be a major obstacle for pedestrians, but a 50 percent reduction in walking speed adds less than 10 seconds of travel, resulting in a relatively trivial difference in the accessibility score. But a project to improve this condition could significantly improve walking accessibility (assuming there were nearby destinations to walk to). So, in a revised approach, impedances will be increased to better reflect those conditions' effects on accessibility. In cases where the median traveler would be significantly discouraged from walking, we will assign 100 percent impedances, essentially "turning off" the links involved.

PeopleForBikes uses this latter approach in their newly developed Bike Network Analysis (BNA) score. Their analysis only considers segments and intersections that meet the lowest levels of traffic stress for bicyclists. "In practical terms," they explain, "this is intended to correspond with the comfort level of a typical adult with an interest in riding a bicycle but who is concerned about interactions with vehicular traffic." This approach encourages the development of complete, connected bicycle networks for the least comfortable riders.[6]

Eventually, other impedances should be developed and accounted for as well. These include:

- Transit wait times (which could be mitigated with next-bus and next-train signs)
- Pedestrian wait times at signalized crossings

- Hills, as impediments to cycling and perhaps walking
- Auto and transit speed variations, or reliability
- Dollar costs for tolls, parking, and transit fares
- "Terminal" time spent parking and walking to a destination

Alternatively, for non-auto modes, we may be able collect enough trip-making attributes on the network that tell us useful information about impedances directly, as we do today with auto speeds. For example, we may be able to discern changes in cycling speeds due to hills or routes avoided by pedestrians, and adjust link attributes accordingly.

Hatchet and scalpel

When we have all the attributes we want attached to all of the links in all of the modal networks, we will be able to figure accessibility gains and losses from changes in the networks very simply. Virginia has built a good amount of detail, including the walking impedances mentioned above, into its networks. Still, when individual projects are being considered, robust analysis may require some manual checking to determine where sidewalks and crossings are properly represented in the networks, and making any necessary fixes, including additions of impedances. In this way, the Virginia team applies the highest level of detail where it matters—the scalpel—while acknowledging that the network as whole—the hatchet—does not have such details. When time is short for assessing a project, the scalpel can be applied by reviewing an online source such as Google Earth and making any necessary changes to the networks.

Work and non-work accessibility

Virginia's Smart Scale, in its original round, operationalized accessibility to employment, because this measure is somewhat simpler than non-work accessibility and because of the intuitive relationship between employment access and economic well-being. However, the majority of household auto miles and trips are to non-work destinations (Table 3), and access to these destination has a clear relationship to outcomes such as housing prices (indicating neighborhoods with better non-work accessibility are more desirable) and auto travel demand (indicating people in neighborhoods with better non-work can meet their needs with less driving, with beneficial effects on personal budgets, state and city infrastructure costs, congestion, and emissions). Therefore, at this writing, the Commonwealth is developing a non-work accessibility score as well.

Table 3. Trip characteristics by trip purpose, derived from the 2009 NHTS for the United States.

Trip purpose	Average household VMT	Percent of household VMT	Average household trips	Percent of household trips
All	19,850	100.0%	2,068	100.0%
Work	5,513	27.8%	457	22.1%
Non-work	14,337	72.2%	1,611	77.9%

As noted, the employment accessibility score is relatively straightforward, involving access to all jobs from affected neighborhoods. In Smart Scale, additional points are also given for access to jobs in low-income neighborhoods.

Calculating non-work accessibility requires additional thought about what POIs are important and how they should be represented. For example, most people expect good access to only one or two grocery stores, but many more restaurants. To develop the proposed Smart Scale score, the team first examined the type and number of POIs accessible by walking from Census blocks throughout Virginia. These were converted into accessibility scores for each neighborhood, with top-scoring neighborhoods rated as 100 and others scored proportionally between zero and 100.

By focusing on walking accessibility, this approach emphasizes local access (unlike access to jobs). This approach assumes that "walkable neighborhoods" are the highest standard, while recognizing that destinations within walking distance are generally accessible by other modes as well.

The POIs used in this approach, along with their weights, are shown in Table 4. The Smart Scale rating, as proposed, will employ both the project-area score assuming completion of the transportation project, on this 100-point scale. Land use planners could use the same scale to identify areas with accessibility deficits or assess the effects of proposed land use changes on accessibility.

Table 4. Proposed non-work accessibility score, based on analysis of neighborhoods throughout Virginia.

Category	Points	Definition
Bank	0.74 each (up to 15 occurrences)	Bank, ATM
Education	5.6 each (up to 2 occurrences)	School
Entertainment	5.6 each (up to 2 occurrences)	Cinema, Performing Arts, Museum, Nightlife, Sports Complex, Convention/Exhibition Center, Sports Center, Animal Park
Food & Drink	0.25 each (up to 45 occurrences)	Restaurants, Coffee Shop, Winery, Bar or Pub
Grocery	3.7 each (up to 3 occurrences)	Grocery
Healthcare	3.7 each (up to 3 occurrences)	Hospital, Medical Service, Pharmacy
Public Services	3.7 each (up to 3 occurrences)	Library, Post Office, Community Center, City Hall, Court House, Police Station
Recreation	3.7 each (up to 3 occurrences)	Golf Course, Ice Skating Rink, Campground, Park/Recreation Area
Shopping	0.34 each (up to 33 occurrences)	Shopping, Convenience Store, Clothing Store, Department Store, Specialty Store, Home Improvement & Hardware Store, Office Supply & Service Store, Bookstore, Home Specialty Store, Sporting Goods Store, Consumer Electronic Store
Total points	**100**	

Interpreting scores
Accessibility can be used in multiple ways, so there is no one way to interpret scores. Even with a dedicated tool like Sugar Access, until the field becomes more standardized, there will be a need to consider how to operationalize metrics that relate to the policy or practice question at hand. For example, an agency might want to scan for important barriers restricting accessibility, and a simple heat map that shows where those hard edges are will suffice. Or, slightly more complicated, it might want to know where the most highly populated low-income neighborhoods with poor transit access to work are. Again a relatively simple output from a tool like Sugar with some additional work in GIS would provide the answers. In another case the agency might want to understand where to invest in first- and last-mile connections to transit using some measure of how circuitous the existing connections to stations are.

This guide focuses mainly on applying accessibility to transportation and land use projects, with examples in the following sections, based on methods developed for Smart Scale. Because that program rates transportation projects for their impact, the process generally (though not always) considers before-and-after scenarios using Sugar Access.

To score a project on access to employment, the Smart Scale process follows these steps:

1. Project boundaries are drawn as buffers around the project extending 60 minutes for transit and 45 minutes for auto (reflecting transit users' propensity to spend more time commuting). These buffers are primarily to simplify analysis and are subject to change.
2. Current access to jobs by auto and transit is calculated for Census block groups in the project area. The transit score includes first- and last-mile walks; where walking access to jobs is more efficient than using transit, it simply counts the walk. As noted, jobs are decay-weighted.
3. Networks are amended to reflect post-project conditions. These could be auto speed increases from capacity improvements, managed lanes, or reduced demand from TDM or transit; new auto, transit or walking routes; improved transit headways; or reduced impedances on walking routes. Many of these changes are provided in project descriptions and input directly into Sugar, with the exception of auto speed changes, which are often modeled and then input as network changes.
4. New auto and transit scores are calculated. This is done just as the baseline calculation was done, but with post-project networks, for the same block groups.
5. Pre- and post-project scores are compared. Pre-project accessibility is subtracted from post-project accessibility to estimate project impacts for each block group. The auto and transit scores are summed.[7]
6. Total project impact is calculated. Scores from Step 5 are multiplied by population in each block group, and the sum of those scores is divided by the total population of the project area.

The proposed method for calculating non-work accessibility changes for projects is similar, except that:

1. It employs a smaller, 3-mile project area (impacts are typically within three miles of the project), and employs data from Census blocks rather than block groups.
2. Instead of calculating accessibility to jobs, by auto and transit, it calculates walking accessibility to the POIs listed in Table 4, resulting in a maximum score of 100.

3. The post-project score is calculated entirely within Sugar Access, as it requires only addition of new walking links or changes to impedances on walking links—no speed modeling necessary.

It is beyond the scope of this report to provide full details on how Smart Scale computes project scores, as these involve criteria other than accessibility. In brief:

1. Employment accessibility scores for proposed projects are compared, with the top score rating 100 and all others receiving proportionate scores down to zero.
2. A similar exercise is done for employment access for low-income residents, with the top project scoring 100 and the rest receiving proportionate scores.
3. (Proposed) Post-project non-work scores are multiplied by future population and employment in the project area and then compared to each other, with the top scoring project rated 100 and others receiving proportionate scores.
4. (Proposed) Post-project non-work scores are multiplied by gain in population and employment to a future date in the project area and then compared to each other, with the top scoring project rated 100 and others receiving proportionate scores.
5. These scores, along with scores for other criteria and subcriteria, are weighted and combined for a total project score.
6. Total scores are divided by the amount of funding requested from the state to provide final project scores and rankings.

Because Smart Scale is a transportation project prioritization process, it does not employ scoring for land use changes. However, such scoring would be relatively straightforward, requiring no modeling outside of the tool:

1. Project areas would be defined.
2. Baseline accessibility would be calculated, for employment or non-work purposes as relevant, for Census geographies in the project area.
3. New land uses would be added as employment or non-work POIs.
4. Post-project scores would be calculated for relevant Census geographies.
5. Pre- and post-project scores would be compared to assess impact in each Census geography.
6. Scores in No. 5 would be summed or averaged across the project area.

Note that for land use, before-and-after scores may be less relevant than simple standards, e.g., a minimum non-work accessibility score for greenfield residential development.

An exciting opportunity for using project-based accessibility scores occurs when an agency seeks to achieve a particular outcome with a project or program. The four modal accessibility scores can be related in a regression equation or algorithm to predict outcomes such as mode choice and VMT. This goes beyond the Smart Scale application, but is described in the final section of this guide.

Accessibility by project (transportation)

This section provides examples of scoring for hypothetical transportation projects using Smart Scale methodologies. Note that when projects are actually scored, the team does not produce heat maps; the ones here are simply to help explain how the scoring works. Also, note that Smart Scale combines modal scores for employment accessibility, while it relies on walk mode for non-work accessibility. For specific details of how those scores are calculated, please see the documentation at vasmartscale.org.

Example 1: Access to employment

In this case, we assess bus line improvements between Norfolk and Virginia Beach in Hampton Roads by reducing morning headways from 30 to 20 minutes. This improvement shortens average travel times along the corridor, increasing the number of jobs accessible based on the travel-time decay function for the region, and theoretically improves ridership. The impacts are concentrated mostly within three miles of the project, but also extend to some more far-reaching neighborhoods. Note that in Smart Scale, this project might also be scored for improvements to auto traffic flows if auto travelers would be diverted to transit.

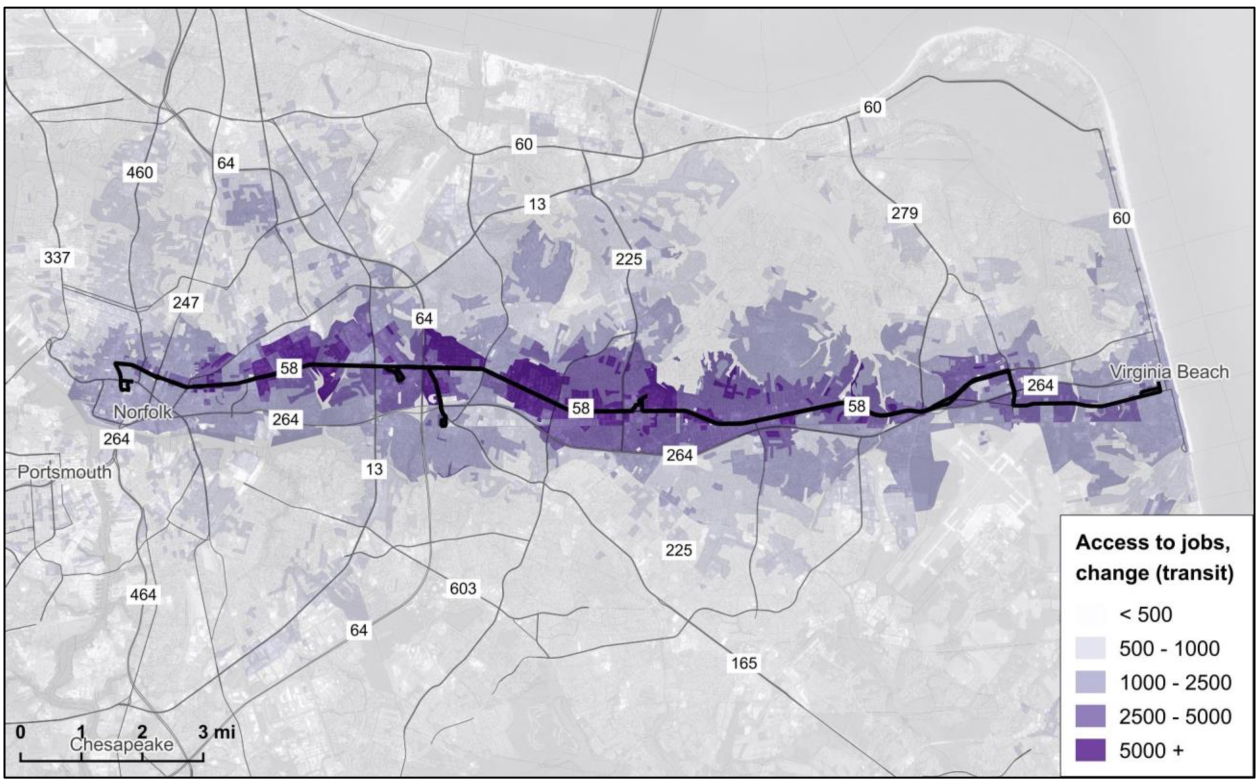

Figure 6. Changes in access to employment resulting from bus line headway improvements.

Table 5 shows how the changes in employment accessibility are weighted for population in Census blocks and averaged. The largest change in a single block group is an additional 10,015 jobs accessible by transit, but that change only affects four people. For the 980,047 people that live within 10 miles, the average impact is 578 additional jobs accessible by transit. (Smart Scale's project area is 45 minutes by transit, so might be different.)

Table 5. Project impact calculations for bus line headway improvements in Hampton Roads.

Access to jobs by transit					Weight (population)	Weighted change
	Block number	Before	After	Change		
Census blocks with greatest change	1	69,236	79,251	10,015	4	40,061
	2	68,838	78,803	9,965	21	209,267
	3	70,434	80,386	9,952	26	258,753
	4	70,171	80,036	9,865	19	187,435
	5	68,443	78,274	9,831	34	334,267
	6	69,306	79,106	9,800	0	0
	7	68,258	77,967	9,709	25	242,728
	8	68,319	77,527	9,207	48	441,955
	9	83,140	91,927	8,787	0	0
	10	80,037	88,753	8,716	35	305,059
				Total	212	2,019,525
				Total for entire project*	980,047	566,065,586
				Average impact of entire project*	578	

**within 10 miles of the project area*

Example 2: Non-work accessibility

In this case, also in Hampton Roads, a scan of existing non-work accessibility reveals a barrier that the Norfolk-Virginia Beach Expressway (SR 264) creates between residents to its south and non-work POIs to its north (Figure 7). A proposed project to improve walking connections would reduce level-of-stress at an existing underpass and add a pedestrian overpass, resulting in noticeable improvements in accessibility using the Smart Scale 100-point scale. (
Figure 8).

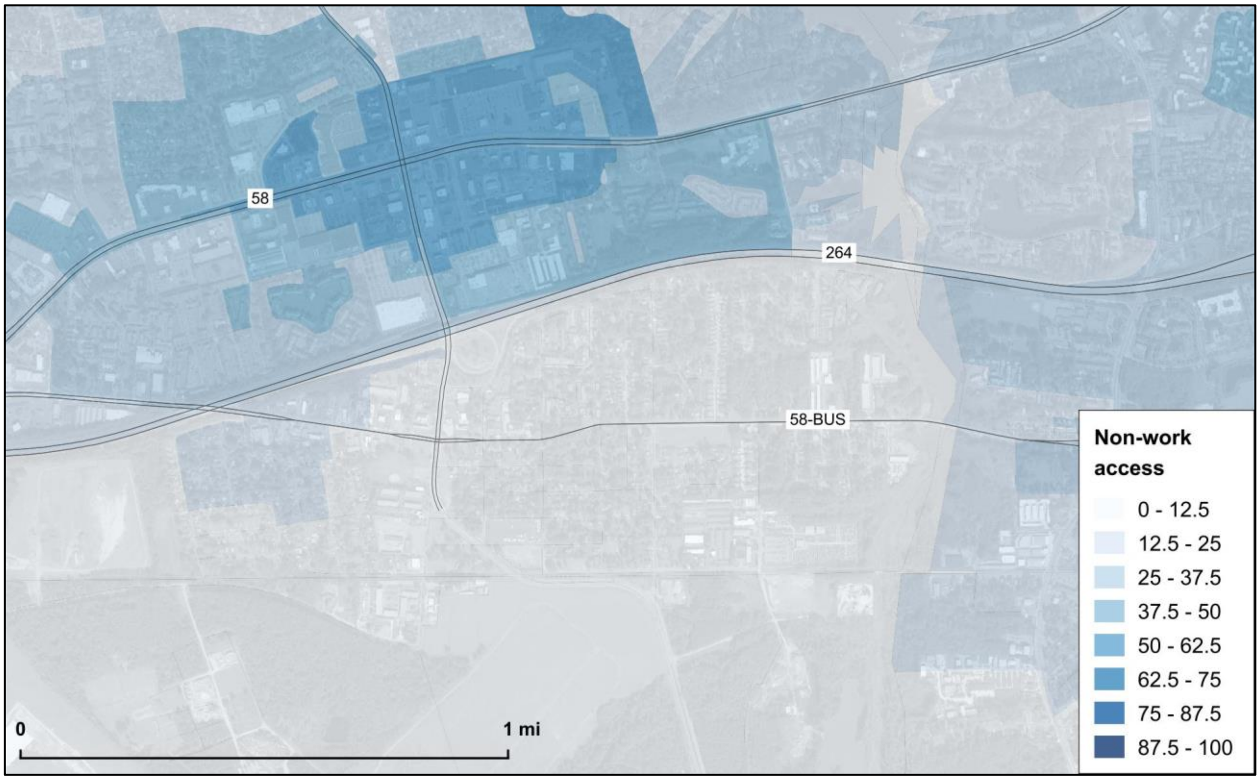

Figure 7. Existing non-work accessibility along the Norfolk-Virginia Beach Expressway, showing a hard break from north to south.

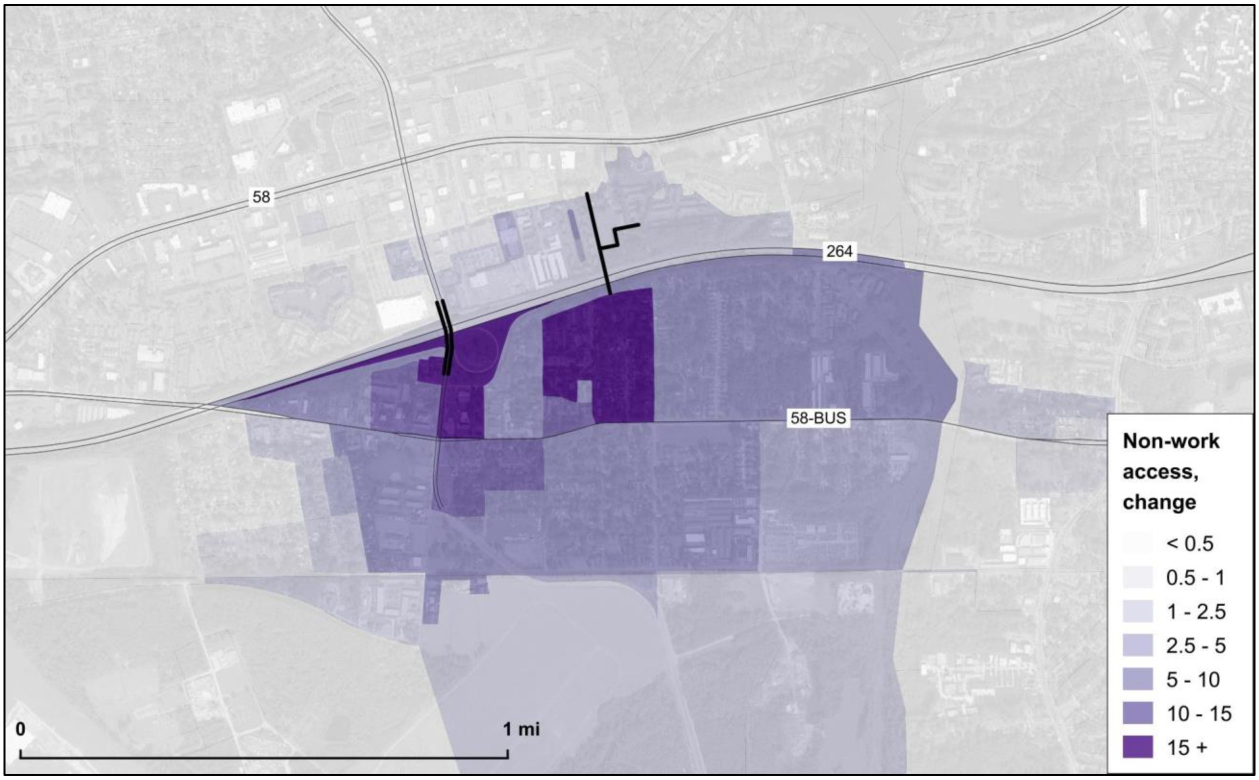

Figure 8. Changes in non-work accessibility resulting from new pedestrian connections along the Norfolk-Virginia Beach Expressway.

Table 6 shows how the changes in non-work accessibility are weighted for population in Census blocks and averaged. The largest change in a single populated block group is an additional 16 points affecting 12 people. For the 67,438 people that live within three miles, the average impact is 0.497. In total, the project adds 33,498 non-work access points.

Table 6. Project impact calculations for pedestrian crossings along the Norfolk-Virginia Beach Expressway.

Pedestrian non-work access					Weight (population)	Weighted change
	Block number	Before	After	Change		
Census blocks with greatest change	1	6	32	26	0	0
	2	6	31	25	0	0
	3	7	31	24	0	0
	4	7	29	22	0	0
	5	8	29	22	0	0
	6	9	25	16	0	0
	7	9	25	16	12	192
	8	5	20	16	203	3,191
	9	6	21	15	487	7,378
	10	10	24	14	4	55
				Total	706	10,817
				Total for entire project*	67,438	33,498
				Average impact of entire project*	0.497	

**within three miles of the project area*

Accessibility by project (land use)

In this case, another hypothetical prepared as an illustration for a planning exercise in the Town of Vienna, the challenge is to improve non-work access for neighborhoods in the town. Current conditions (Figure 9) show that accessibility is high along the town's main street (Maple Avenue/SR 123) but lower in many neighborhoods.

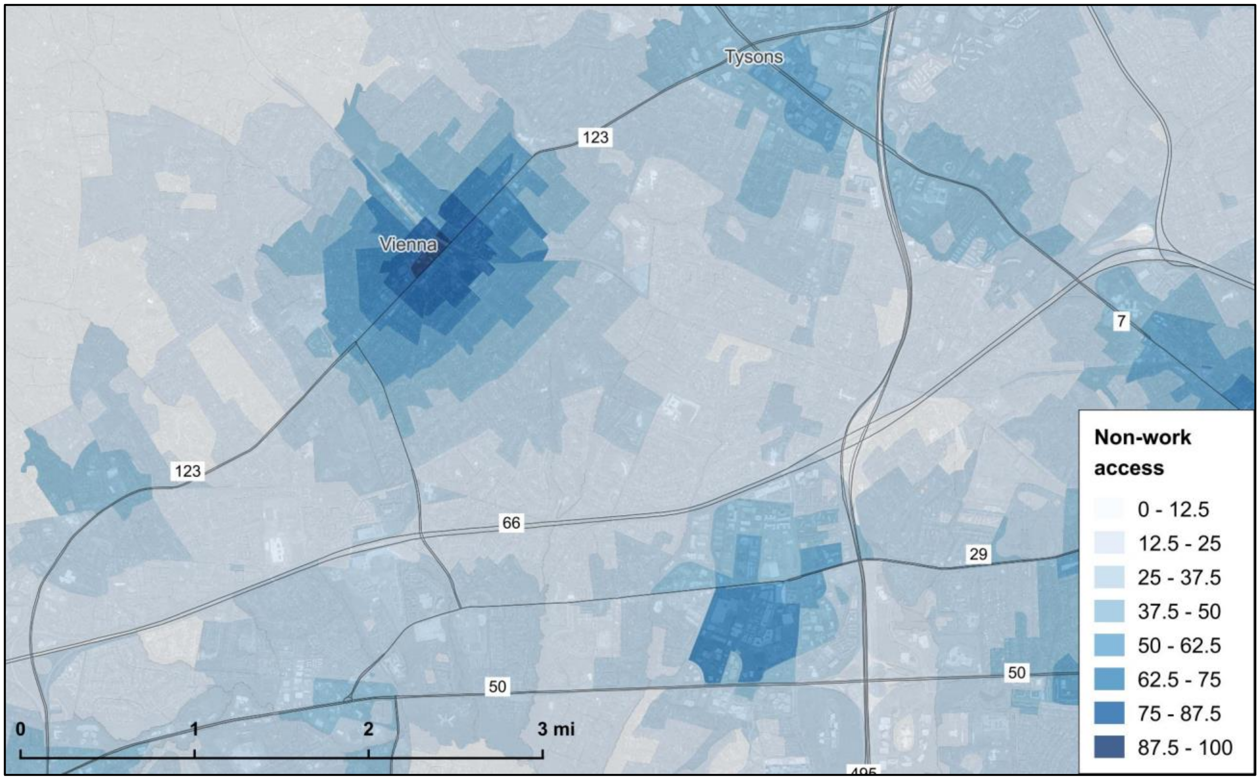

Figure 9. Existing non-work accessibility in the Town of Vienna.

A separate analysis looked at filling gaps in the walking network at a former railroad track that now serves as a bike path, and it found some gains. This analysis considers land use changes—recruiting new businesses to an underused commercial area on the southern edge of town. The proposed development includes two restaurants (these could also be cafés or bars), a small grocery store, a bank or ATM, entertainment venue (such as a theater or art house), and four shops. The non-work accessibility improvements (Figure 10) far exceed those provided by the transportation improvement considered (which does not mean, however, that those relatively inexpensive improvements should not go forward).

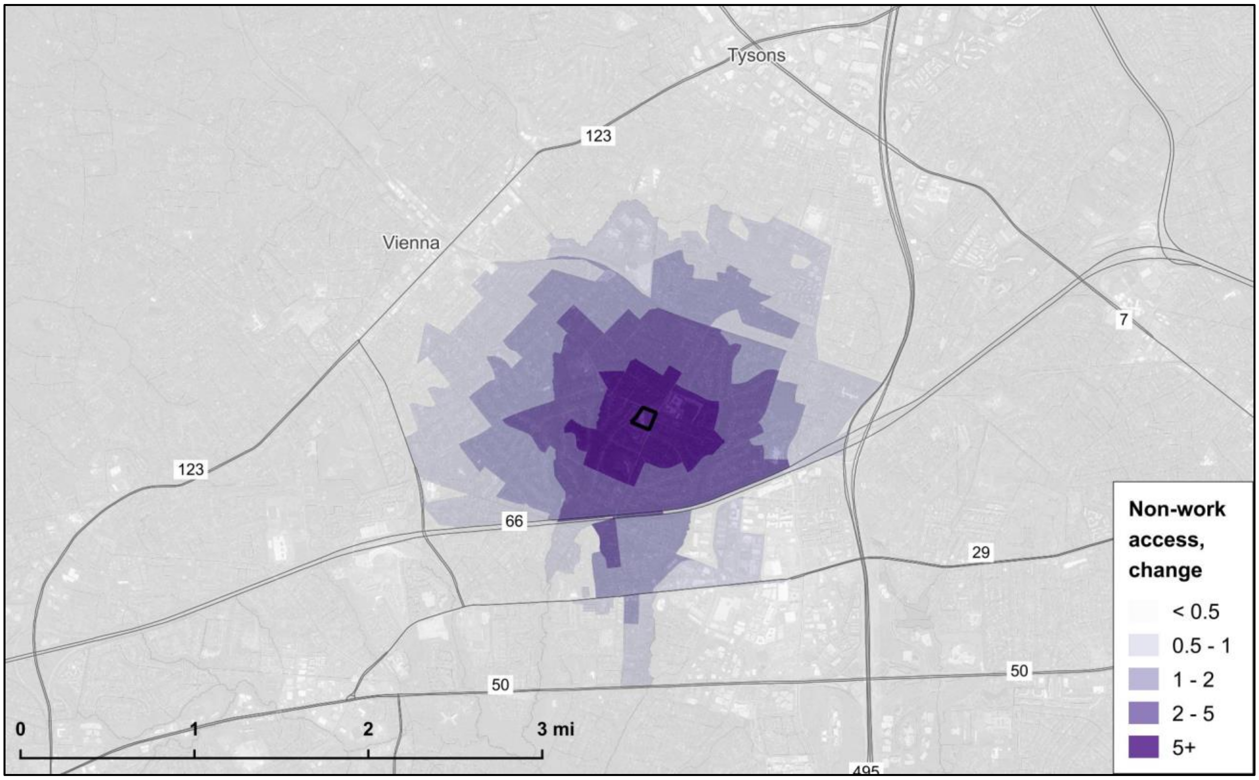

Figure 10. Changes in non-work accessibility resulting a new mixed-use development on the southern edge of the Town of Vienna.

Table 7 shows how the changes in non-work accessibility are weighted for population in Census blocks and averaged. The largest change in a block group is an additional 12 points affecting 691 people. For the 144,408 people that live within three miles, the average impact is 0.337. In total, the project adds 48,641 non-work access points.

Table 7. Project impact calculations for land use development project in Town of Vienna.

<table>
<tr><th colspan="5">Pedestrian non-work access</th><th rowspan="2">Weight (population)</th><th rowspan="2">Weighted change</th></tr>
<tr><td rowspan="12">Census blocks with greatest change</td><td>Block number</td><td>Before</td><td>After</td><td>Change</td></tr>
<tr><td>1</td><td>29</td><td>41</td><td>12</td><td>691</td><td>8,181</td></tr>
<tr><td>2</td><td>29</td><td>41</td><td>12</td><td>0</td><td>0</td></tr>
<tr><td>3</td><td>29</td><td>40</td><td>11</td><td>0</td><td>0</td></tr>
<tr><td>4</td><td>28</td><td>38</td><td>10</td><td>40</td><td>410</td></tr>
<tr><td>5</td><td>27</td><td>37</td><td>10</td><td>0</td><td>0</td></tr>
<tr><td>6</td><td>29</td><td>38</td><td>10</td><td>0</td><td>0</td></tr>
<tr><td>7</td><td>28</td><td>37</td><td>10</td><td>531</td><td>5,098</td></tr>
<tr><td>8</td><td>23</td><td>32</td><td>8</td><td>107</td><td>902</td></tr>
<tr><td>9</td><td>29</td><td>37</td><td>8</td><td>0</td><td>0</td></tr>
<tr><td>10</td><td>25</td><td>32</td><td>8</td><td>0</td><td>0</td></tr>
<tr><td colspan="4">Total</td><td>1369</td><td>14,591</td></tr>
<tr><td colspan="5">Total for entire project*</td><td>144,408</td><td>48,641</td></tr>
<tr><td colspan="5">Average impact of entire project*</td><td colspan="2">0.337</td></tr>
</table>

**within 3 miles of the project area*

Using accessibility to predict outcomes

Modal accessibility scores by themselves can help advance various policy goals. As discussed above, we know that better walking-scale accessibility to non-employment destinations is associated with lower VMT and associated costs and higher property values, indicating more desirable quality of life. Indeed, Virginia's Smart Scale process relies on these modal accessibilities, either in tandem (auto and transit for employment accessibility) or for a single mode (walking for non-employment accessibility).

Accessibility offers additional power when modal scores are compared. Sometimes more useful than the scores themselves are the relationships among the scores. Consider the following illustration involving three neighborhoods in the Washington, DC, area. The most urban example is Logan Circle in central Washington, DC; it has the highest levels of density, mix of uses, transit service, and walking and biking facilities. At the other extreme is a suburban neighborhood in McLean, VA, that is mostly residential with commercial and public land uses clearly separated from housing by zoning, has a sparse street network with little grid connectivity, and lacks walking access to the Metrorail system. In the middle is Clarendon, an older community in Arlington County, VA, that has grown dramatically as a mixed-use center around its eponymous Metrorail station.

When we calculate these areas' access to employment, we get the results shown in Figure 11. Clearly, auto accessibility is higher than other modes in all three cases, and—what may seem counterintuitive at first glance—the highest score occurs in Logan Circle, perhaps one of the most transit-, walking- and biking-friendly areas in the region. The explanation for this is fairly straightforward: Logan Circle lies in the center of the region and thus has the most complete access to regional opportunities of any location, regardless of mode.

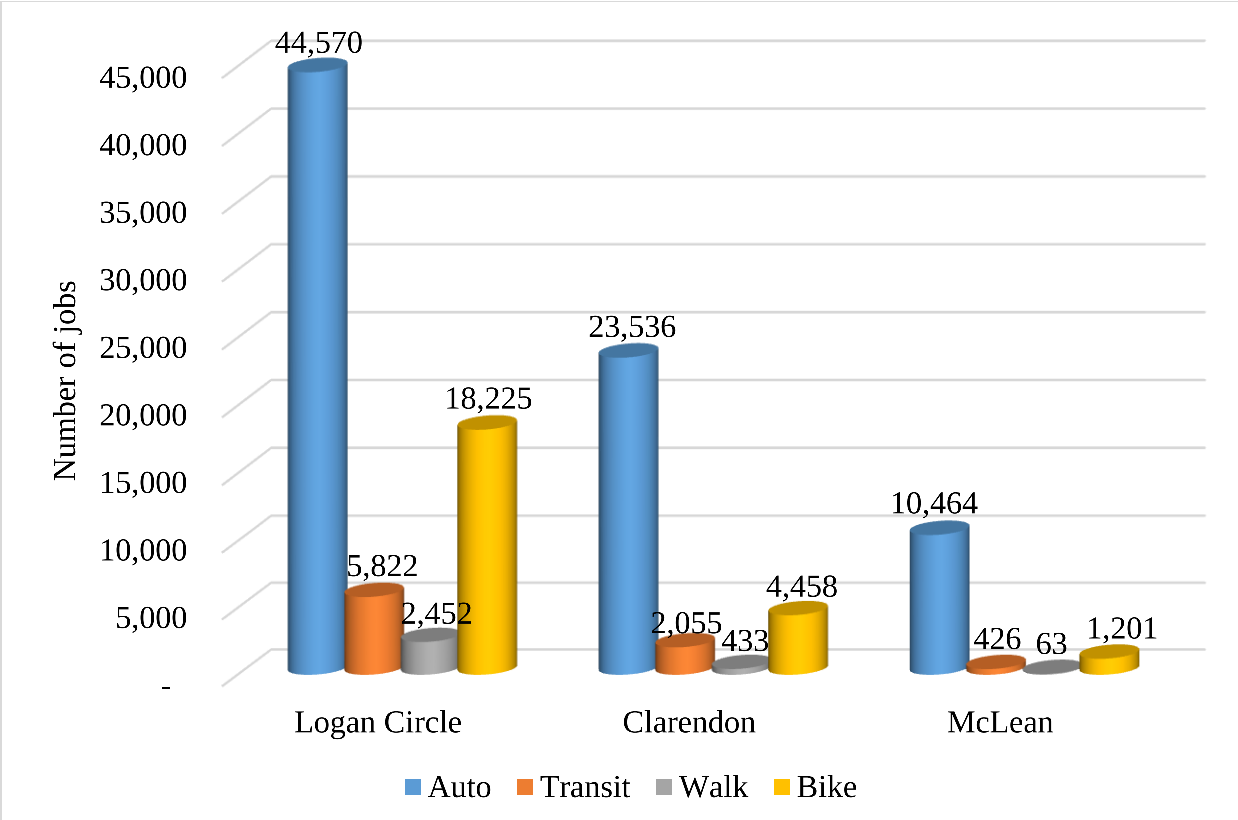

Figure 11. Modal accessibilities for three Washington, DC area neighborhoods. (Renaissance Planning Group)

So, does higher auto accessibility lead to greater auto use? Not necessarily. It all depends on the *relative accessibilities*. Table 8 indicates that while the auto accessibility score for Logan Circle exceeds that of McLean by a factor of 4.26 to 1, transit accessibility is greater by a ratio of 13.6 to 1, bicycle by 15.2 to 1, and walking by 38.9 to 1. A similar dominant relationship exists between Clarendon and McLean, though proportionately much less than when compared with Logan Circle.

Table 8. Modal accessibilities using suburban McLean as a baseline.

Comparative accessibilities			
	Logan Circle	Clarendon	McLean
Auto	4.26	2.25	1.0
Transit	13.60	4.82	1.0
Bike	15.17	3.71	1.0
Walk	38.90	6.90	1.0

Table 9. Bike/walk mode shares for three neighborhoods.

Non-motorized mode share (household travel survey)	
Logan Circle	41%
Clarendon	21%
McLean	8%

When these relative accessibility relationships are compared to modal shares for the same areas (Table 9), we see that active transportation use is higher where walking and biking accessibility are high relative to auto accessibility. This implies that planners or transportation agencies can improve non-auto mode shares—to mitigate congestion or emissions, to improve public health or for other policy reasons—by raising those accessibilities in relation to automobiles, through such measures as:

- Locating more jobs and housing within walking distance of quality transit service
- Paying particular attention to the walking and bicycle access links to transit
- Ensuring that walking and biking within activity centers is as safe and efficient as possible (short blocks, frequent crossings, less emphasis on maintaining vehicle speeds on the street network)

To provide a bit more insight into the way relative accessibilities influence behavior, Table 10 from another Washington, DC-area project shows the average scores for accessibility to jobs at the home location of people's commute in relation to the actual commute mode they chose, according to travel survey responses. For those who walk to work, walking accessibility is 2.9 times the average and transit accessibility is 1.7 times the average. For those who walk to transit, walking accessibility is 1.7 times the average and transit accessibility is 1.5 times the average. For those who drive alone, walking and transit accessibility are well below average. Knowing the level of accessibility at the work end of the trip is equally as insightful.

Table 10. Employment accessibility by mode taken relative to average accessibilities for all commuters.

Primary commute mode (household travel survey)	Access to jobs at home location (avg. = 1)		
	By auto	By transit	By walking
Drive alone	0.96	0.86	0.80
Auto passenger	1.03	0.99	0.76
Transit (auto access)	0.89	0.67	0.49
Transit (walk or feeder access)	1.13	1.47	1.68
Walk	1.20	1.71	2.85
Bicycle	1.10	1.21	0.97
Other	0.84	0.83	0.40
Average	**1.00**	**1.00**	**1.00**

It is possible to employ relative accessibility scores to predict outcomes such as mode choice and household VMT. The mode share regression model in Table 11 was developed using the same Washington, DC-area data summarized above. It predicts mode shares for commute travel using modal accessibility scores for three primary modes: auto, transit and walk. A similar model, not shown, predicts non-work travel modes, and others were developed to predict VMT.

Table 11. Model using relative accessibility to predict mode shares.

	Commute mode share (*t*-statistics in parentheses)			
	Auto	Drive-to-transit	Walk-to-transit	Walk
Constant	0.826 (94.600)	0.116 (21.700)	0.052 (6.510)	0.003 (1.260)
Auto accessibility	1.380E-07 (9.350)	-1.21E-08 (-1.340)	-1.23E-07 (-8.976)	
Transit accessibility	-1.45E-06 (-27.000)	-2.58E-07 (-8.030)	1.41E-06 (29.100)	2.98E-07 (16.087)
Walk accessibility	-6.71E-06 (-6.840)	-1.11E-06 (-1.850)	-1.23E-07 (-8.976)	1.89E-06 (4.260)
R^2	0.788	0.313	0.830	0.327
Estimated mode share at mean	**0.657**	**0.057**	**0.205**	**0.062**

With such models, it is possible to go to any area—as small as a census block —and, given accessibility scores, estimate what the current modal split and VMT are. Similarly, these models can estimate impacts of policies or projects, such as calculating the accessibility scores from land use or infrastructure changes and modeling the probable outcomes. This can be useful, for example, if a transportation or land use agency has a mode-shift or SOV demand reduction goal; projects and programs can be assessed for whether they advance toward or retreat from such goals. Moreover, such models may help determine to what extent a new facility (pedestrian link, transit route, etc.) will be used by calculating the relative change in modal accessibility it provides.

Endnotes

[1] Wachs, Martin; Kumagai; T.Gordon. Physical accessibility as a social indicator, Socio-Economic Planning Sciences, 1973, Vol.7(5), pp.437-456

[2] Ibid.

[3] While a minute is a minute (mostly), types of costs vary widely. There are fixed (vehicle insurance) and variable (gasoline) costs, personal (vehicle ownership) and societal (infrastructure) costs, as well as costs that are obvious (gasoline) and costs that are less obvious (vehicle depreciation).

[4] For discussion about this concept as related to bicycling, see MTI 11-19. http://transweb.sjsu.edu/PDFs/research/1005-low-stress-bicycling-network-connectivity.pdf

[5] Other tools include Network Analyst (part of ESRI ArcGIS), Conveyal, OpenTripPlanner, UrbanAccess, and PeopleForBikes' Bike Network Analysis.

[6] https://bna.peopleforbikes.org/

[7] Though not current practice for Smart Scale, it may be desirable to net out accessibility changes, e.g. for a new highway grade separation that impedes walking access to transit.