State Smart Transportation Initiative

MEASURING ACCESSIBILITY

A GUIDE FOR TRANSPORTATION AND LAND USE PRACTITIONERS

By Eric Sundquist, Chris McCahill, and Michael Brenneis

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Any errors or other shortcomings are the responsibility of the authors.

DEFINITION OF TERMS

Accessibility has not yet been established in practice with standard terms and metrics. These terms are consistent with emerging practice, but the reader may find other language in other sources.

Accessibility: The ease with which people may reach destinations such as jobs, stores, parks, schools (sometimes referred to as "opportunities"). "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 opportunity metrics: A method of computing accessibility by summing the number of destinations that a traveler can reach, often within a given time limit.

Isochrone: A spatial depiction of the area covered by a cumulative opportunity metric within a given time threshold.

Decay-weighted metrics: Decay-weighting is similar to cumulative opportunity metrics but, instead of a hard cutoff, destinations count for less the longer they take to reach.

> **Decay curve:** A curve or function used in computing accessibility that reflects people's propensity to travel in relation to travel time.

> **Gravity:** A form of decay-weighting commonly used in demand models.

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

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.

Network: A digital representation of the four means of travel: walk, bike, transit, and auto. Networks are typically represented as segments (links) that represent not only their place on the map but also particular attributes such as auto speeds or pedestrian levels of stress, and connections between those links (nodes).

Opportunity: A term commonly used in place of "destinations," "jobs" or other specific attributes of different land uses.

Point of interest (POI): 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).

Vehicle miles traveled (VMT): A measure of the number and length of motor vehicle trips, e.g. by a household or metro area. VMT affects multiple outcomes of policy interest, including congestion, air emissions, and personal transportation costs.

PREFACE

Accessibility, aka "destination access" or "access to destinations," has been a topic in research for decades, with the volume of papers growing at an accelerated pace. Fueled by improved data and computing power, this interest has begun to inform transportation and land use practice as well. At least two commercial providers offer platforms for accessibility analysis. Still, practitioners seeking to apply accessibility to decision-making face a fairly daunting task. To our knowledge there exists no concise guide for doing so—until now.

To be clear, there are many resources that students and practitioners can turn to for the foundational theories and advanced analytic techniques behind accessibility analysis, including: David Levinson's paper, "Towards a general theory of access" (*1*); a book, *From Mobility to Accessibility*, by Jonathan Levine, Joe Grengs, and Louis Merlin (*2*); and the recently published *Transport Access Manual*, by David Levinson and a committee of leading researchers and practitioners in the field (*3*). There has also been great work to advance accessibility analysis at a national level, including the U.S. EPA's Smart Location Database[1] and annual reporting by the Accessibility Observatory at the University of Minnesota.[2]

This guide is consistent with the principles and methods in those materials, and it draws heavily from them. But it fills a more basic need by providing a common way of thinking about practice in accessibility, based on real-world use cases, including those undertaken by our project team at the State Smart Transportation Initiative (SSTI) in support of DOTs, MPOs, and local governments throughout the U.S. To that end, it focuses specifically on access for personal surface transportation in urbanized areas, with applications for both transportation and land-use decision-making. It does not address freight, air or interregional access, although many of the concepts apply in those other cases.

Because the bulk of SSTI's work revolves around transportation, we emphasize those applications and relevant examples from that field. But better proximity replaces the need for transportation, and so in many cases the most sustainable solutions to providing accessibility run through land-use decisions. We hope this guide will accelerate the adoption of accessibility analysis and, as a result, wiser transportation and land-use decisions made in tandem.

We look forward to exciting new practice that will emerge, which we track on our blog at ssti.us. We invite comments on this guide at accessibility@ssti.us.

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[1] More information at https://www.epa.gov/smartgrowth/smart-location-mapping

[2] More information at http://access.umn.edu/

HOW TO USE THIS BOOK

Readers who follow the book from beginning to end will have a solid understanding of why accessibility matters, what is required to measure accessibility, how to interpret and report accessibility findings, and how to apply these findings to decision-making. The guide need not be read sequentially nor in its entirety, however. Technically oriented practitioners may want guidance on a particular issue, and policy makers may only want to read the opening and closing sections.

The book is organized as follows:

- **MOTIVATION.** This chapter addresses the need for accessibility measures in transportation and land practice, pointing to problems with existing metrics and standards and providing examples of how accessibility is beginning to inform decision-making. It introduces the cumulative opportunities metric for auto, transit, biking, and walking modes.
- **TRANSPORTATION DATA.** This chapter describes the types of transportation data that are useful in calculating accessibility, with suggestions on how to obtain and use them.
- **LAND USE DATA.** Similarly, this chapter describes the types of transportation data that are useful in calculating accessibility, with suggestions on how to obtain and use them.
- **METHODS AND TOOLS.** This chapter describes ways practitioners can employ the data in the previous chapters to calculate and report accessibility, and to translate accessibility into travel behavior outcomes such as vehicle-miles traveled and modal usage.
- **EXAMPLE ANALYSES.** This chapter walks through a hypothetical accessibility analysis, step-by-step, in order to illustrate the points made in the previous sections.
- **CONCLUDING REMARKS.** This chapter returns to some of the themes of the motivation section, with an emphasis on applying the analytics covered in the rest of the guide.

THE AUTHORS

Eric Sundquist is director of SSTI. Chris McCahill is deputy director of SSTI. Michael Brenneis is a senior research at SSTI. All are located at the University of Wisconsin-Madison. SSTI is a project of UW-Madison and Smart Growth America. For more information go to ssti.us.

MOTIVATION

At the start of World War II, the U.S. and its allies faced an infrastructure problem: Many of their planes were being shot down, so they needed better armor. Armor was heavy, however, so the improvements had to be strategic—just enough to do the job without affecting the planes' performance.

The military collected data on the number and location of bullet holes in returning planes. From there the decision was obvious: Put the armor where the most bullet holes were found—the wings.

And this was exactly the wrong call.

The analysts were measuring the wrong thing. Planes with holes in the wings made it back to base; planes shot in the engines were going down. Fortunately, a more sophisticated analyst realized the problem, and plans changed to put the armor in the right place, saving many lives and helping to win the war (*4*).

The point for us is that measuring the obvious thing and basing decisions on that measure can go disastrously wrong. And that brings us to transportation, where in some ways we are losing the war.

Since 1956 we've spent $10 trillion (in current dollars) on highways in the United States—double the combined cost of transit, intercity rail, aviation, and ports combined (*5*). And for that astronomical sum we have 2.9 million deaths (*6*); streets, roads, and bridges that are commonly described as "crumbling;" epic and ever-growing highway congestion; and the single largest sectoral contributor of climate pollution.

Our transportation system suffers these problems in large part due to its orientation to measures that seem obvious but can lead in the wrong direction. For example, planners and engineers have long judged the success of the transportation system on the speed of cars, based on a scale called "level of service" (LOS). The decision rule is obvious: when cars are slow, or forecasted to be slow due to urban development, add more roadway capacity to speed them up.[3]

Now we have ample evidence that this approach is both ineffective and costly. Wider roads have a paradoxical effect. They generate new traffic in several ways: by luring

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[3] LOS measures for other modes exist, but these are not used nearly as often and are incompatible with auto LOS, making it difficult to evaluate LOS across modes. However, LOS and similar metrics are not without their uses. Speed of travel is a factor in accessibility. And a variation of LOS for walking and biking—"level of traffic stress" —will turn out to be a key component of accessibility metrics for those modes.

more drivers onto the road more often; by making trips by foot, bike or transit difficult or more dangerous; and by fostering development that is more spread out. As well, new capacity in one area can simply move congestion downstream or shift new development entirely. As a result, highway widenings tend to provide little or only temporary relief, while imposing long-term burdens such as higher costs; longer travel distances; and diminished environmental, safety and quality of life outcomes.

These burdens have hit low-income workers and communities of color especially hard. Many historically Black communities, for instance, have been displaced, cut off, or directly impacted by crashes and pollution from nearby highway projects. Meanwhile, many low-income workers who could once reach their jobs with minimal investments, must now own, maintain, and fuel their own vehicles, eating up large chunks of their income. Those who can't or don't want to buy a car must try to find, get, and keep a job that can be reached by other means, often in far-flung places without transit service.

As with World War II aviation, measuring the right thing doesn't guarantee that we will avoid all bad outcomes. Allied planes were still shot down even with efficient armor. But smarter assessments give us a better chance at lowering costs and improving outcomes. The metric we address in this guide is "accessibility."

MEASURING WHAT MATTERS

Accessibility,[4] sometimes called "access to destinations" or "access to opportunities," is a measure that better captures what we want out of our transportation system than does LOS alone. Accessibility describes how easily travelers can reach destinations. To do this, it must go beyond just the speed of travel to also include locations of destinations. If we have a transportation system operating at a high LOS, but destinations that are sparse or distant, we may still have poor accessibility. Conversely, we may also have poor LOS but very dense and close-by destinations, resulting in good accessibility. Of course, the best accessibility case is a well-functioning transportation system and short travel distances.

And when we have good accessibility, we can be more confident about a variety of good policy outcomes. The notion of economic benefit from metropolitan agglomeration rests not on the speed of traffic, but on accessibility. In 1973, Martin Wachs and T. Gordon Kumagai (*7*) defined accessibility just as we do today—"the ease with which citizens may reach a variety of opportunities for

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[4] Confusingly, "accessibility" and "access" can have multiple meanings in transportation parlance. We may describe facilities that allow wheelchair use to be "accessible," for example, and we may talk about grade-separated highways as "limited access." However, "accessibility" as used in this guide has a long history as well, and until "destination access" or some other term catches on, will probably be the default language for the concepts considered here.

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.*

We can see this directly when looking at housing prices; people tend to place value on better accessibility (*8–10*). Beyond the economic outcomes, when we look at accessibility, we see clear associations with levels of driving (*11–14*). This in turn affects emissions, congestion, and transportation costs, among other policy-relevant outcomes.

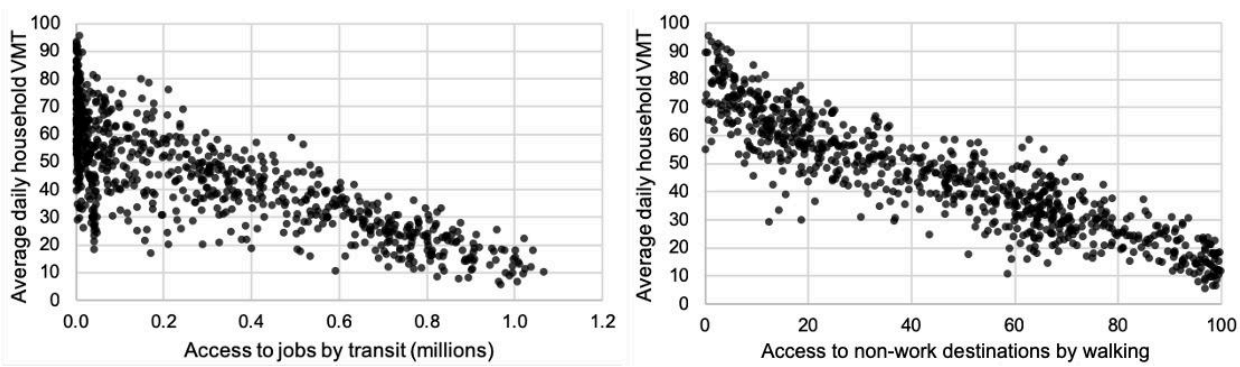

Figure 1. Access by transit and walking (regional and local) is negatively associated with average VMT across households in greater Boston. Source: SSTI.

Measuring accessibility has many practical advantages as well, including:

- It measures what travelers care about—how readily they can meet their needs. This accounts for vehicle speed but also the distance of trips and other barriers, so it can be superior to conventional speed-focused measures in guiding decisions.
- It provides a common measure for assessing various transportation modes and modal investments. 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 provides a common platform for considering land use and transportation questions. Transportation networks and land uses can both be modified, e.g., during scenario planning, and evaluated for accessibility.
- It can be scaled up or down to encompass site and neighborhood access or regional and statewide access. The impacts of small transportation projects are

invisible in many conventional travel analyses, so accessibility can help fill that gap and remove a bias toward supporting larger projects over smaller ones.

- 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 different times of day, and walking accessibility can reflect pedestrian comfort or perceived hazards using concepts like "level of traffic stress." Fine-grained land use data allow the drawing of important distinctions, e.g., between convenience stores and grocery stores when considering food deserts.
- It makes sense to non-technical stakeholders. Where models often rely on numerous assumptions and complex calculations, accessibility simply describes travel times.
- It can be calculated with relatively little training. Several applications let users manipulate transportation and land use data and run analyses using standard GIS or similar platforms.
- Accessibility calculations are relatively quick compared to, say, running scenarios in travel demand models. As such, they can be used to assess multiple scenarios in a short time. (Caveat: To precisely assess the impact of a transportation project, we will need predicted travel speed changes, which may come from travel demand or traffic-simulation models.)
- It can be used to predict outcomes. While accessibility analysis does not replace predictive models that distribute trips throughout networks, 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 development project, design of a highway, transit service improvements, or development of an area or corridor plan—to determine how those decisions advance policy goals.

In other words, accessibility measures can be used in both transportation and land-use decision-making to:

- evaluate existing conditions,
- scan for problems,
- assess various potential solutions,
- track conditions over time as performance measures, and
- communicate to non-technical decision makers or stakeholders at any point in this process.

EXAMPLES

While most of the past work in accessibility analysis to been in academic research, the concept has recently begun to show up in practice as well. Here are a few examples.

SMART SCALE (VIRGINIA)[5]

To allocate funding for highway, active transportation, transit, and transportation demand management facilities, Virginia's Office of Intermodal Planning and Investment (OIPI) uses SMART SCALE to score proposals across a variety of criteria. One of those criteria is the amount to which a project improves access to jobs. In addition, OIPI's SMART SCALE evaluates projects in metro areas on a land use criterion, which is operationalized as walking access to non-work destinations.

SMART SCALE Area Type A														
Factor	Congestion Mitigation		Safety		Accessibility			Economic Development			Environment		Land Use	
Measure	Increase in Peak Period Person Throughput	Reduction in Peak Period Delay	Reduction in Fatal and Injury Crashes	Reduction in Fatal and Injury Crash Rate	Increase in Access to Jobs	Increase in Access to Jobs for Disadvantaged Populations	Increase in Access to Multimodal Travel Choices	Square Feet of Commercial/Industrial Development Supported	Tons of Goods Impacted	Improvement to Travel Time Reliability	Potential to Improve Air Quality	Other Factor Values Scaled by Potential Acreage Impacted	Transportation Efficient Land Use	Increase in Transportation Efficient Land Use
Measure Value	1,328.5 persons	141.6 person hrs.	348.7 EPDO	295.8 EPDO / 100M VMT	257.2 jobs per resident	350.1 jobs per resident	6,642.3 adjusted users	662,863.6 thousand adj sq. ft.	0.0 thousand adj daily tons	353,692,401.8 adj. buffer time index	7,306.6 adjusted points	11.6 scaled points	179,296.3 access * pop/emp density.h	40,876.2 access * pop/emp density change.
Normalized Measure Value (0-100)	4.7	2.2	100.0	0.6	4.5	6.0	23.7	3.4	0.0	8.1	51.6	35.0	13.5	11.6
Measure Weight (% of Factor)	50%	50%	100%	0%	60%	20%	20%	60%	20%	20%	50%	50%	70%	30%
Factor Value	3.5		100.0		8.7			3.6			43.3		12.9	
Factor Weight (% of Project Score)	45%		5%		15%			5%			10%		20%	
Weighted Factor Value	1.6		5.0		1.3			0.2			4.3		2.6	
Project Benefit	15.0													
SMART SCALE Cost	$50,000,000													
SMART SCALE Score (Project Benefit per $10M SMART SCALE Cost)	**3.0**													

Figure 2. A scorecard for a project evaluated for funding under the SMART SCALE program. Source: Virginia OIPI.

ACCESS TO CORE SERVICES (DETROIT METROPOLITAN AREA)[6]

The Southeast Michigan Council of Governments (SEMCOG), the Detroit-area MPO, has benchmarked access to seven core services—fixed-route transit, jobs, health care facilities, supermarkets, parks, schools, and libraries. This work is intended "to develop common measures of accessibility for comparison across the region, establish benchmarks to identify gaps and challenges where accessibility is low, set regional policies and local actions to be implemented by various stakeholders, and integrate accessibility measures and policies into regional transportation planning and decision-

[5] More information at http://vasmartscale.org/

[6] More information at https://semcog.org/access

making processes." A gap, for example, might be a lack of walkable or transit-accessible food stores in an area where residents have few cars.

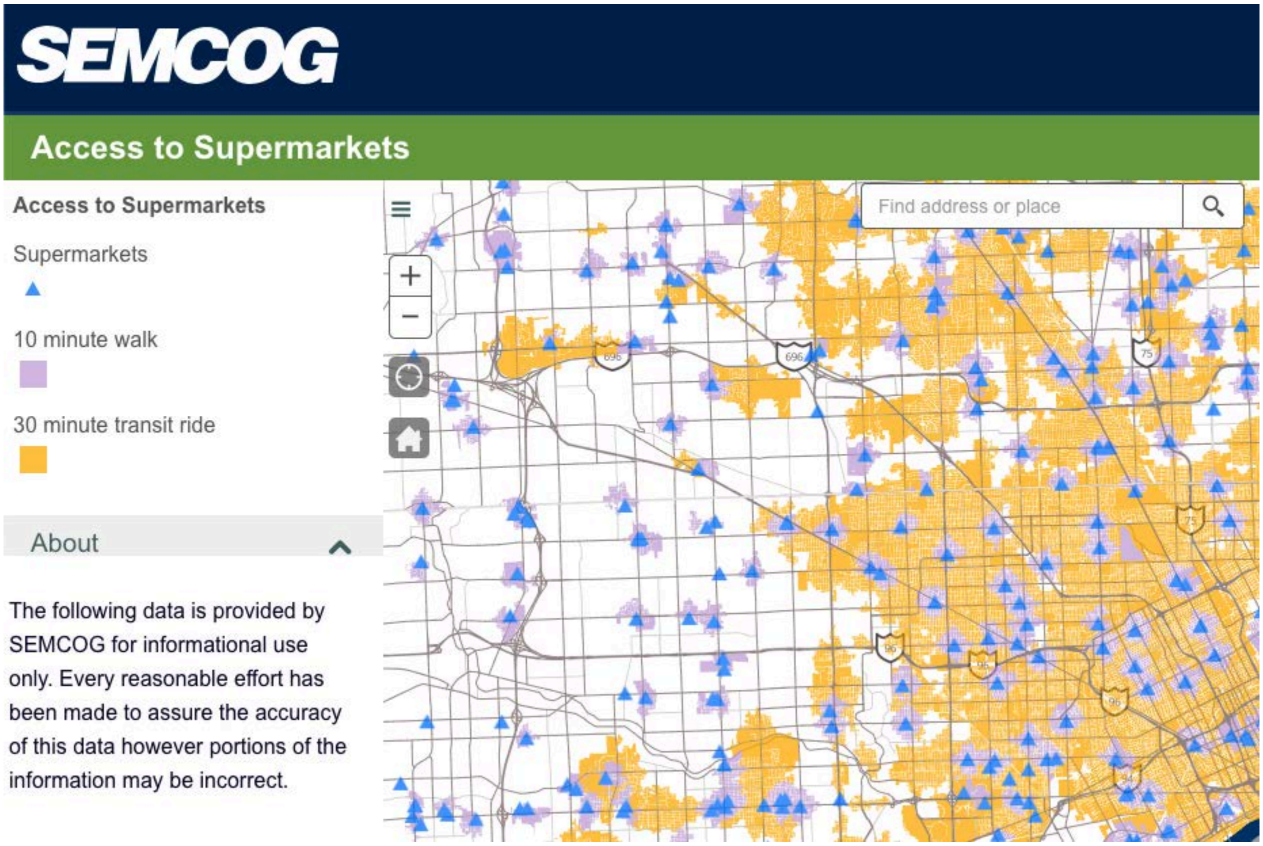

Figure 3. Supermarket access as a component of access to core services analysis. Map depicts areas with walks of 10 minutes or less (purple) and transit rides of 30 minutes or less (yellow) to supermarkets. Source: SEMCOG.

SMARTTRAC (HAWAII)[7]

Like Virginia's SMART SCALE, Hawaii DOT's SmartTRAC (for Transportation Rank Choices) assesses proposed projects across a variety of policy-driven criteria. Accessibility is included, but in a different way than in Virginia. Responding to a policy goal of reducing single-occupancy vehicle travel, SmartTRAC awards points for projects that improve accessibility by non-auto modes, in line with a policy goal to reduce single-occupancy vehicle mode share.

[7] More information at https://hidot.hawaii.gov/wp-content/uploads/2019/06/2019-Honolulu-City-Council.pdf

Figure 4. Accessibility analysis for SmartTRAC ranked a pedestrian connection between two neighborhoods as the best project in the state—the one most likely to reduce single-occupancy vehicle mode share based on non-auto modal accessibility and cost. Source: SSTI.

LOCAL ACCESS SCORE (BOSTON METROPOLITAN AREA)[8]

The Metropolitan Area Planning Council (MAPC) has calculated the walking and biking accessibility provided by all of the roadways in the Boston area—how well each link connects people with schools, shops, restaurants, parks, and transit stations. Stakeholders can see these findings in interactive maps, assisting in decision-making around planning, project selection, maintenance, enforcement, and more. For example, decision-makers may wish to improve walking and biking facilities or impose traffic calming on particularly critical active transportation segments.

[8] More information at http://localaccess.mapc.org/

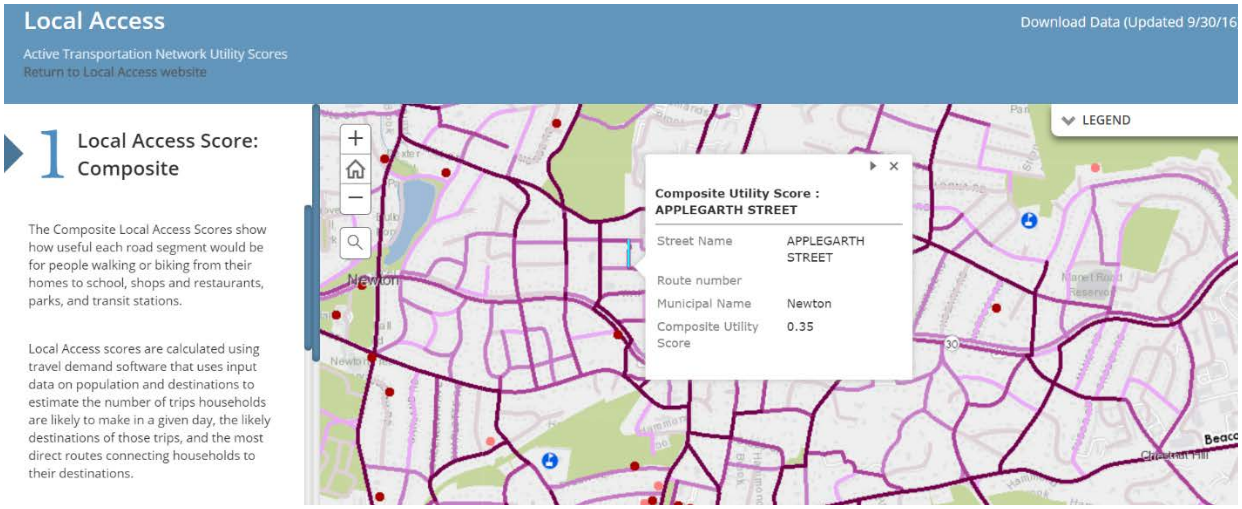

Figure 5. The Local Access tool grades all roadway links on their utility in providing walking and biking access to destinations. The tool also provides walk and bike scores separately. Source: MAPC.

ACCESS TO OPPORTUNITIES (SALT LAKE CITY METROPOLITAN AREA)[9]

The Wasatch Front Regional Council (WFRC), the Salt Lake City-area MPO, has developed several measures of Access to Opportunities (ATO), which it uses in developing its long-range Regional Transportation Plan, its Transportation Improvement Program, and in other planning applications. These include regionally focused measures of access to jobs by auto and transit, developed using its travel model, and local measures of access to core services, developed in GIS.

[9] More information at https://wfrc.org/maps-data/access-to-opportunities/

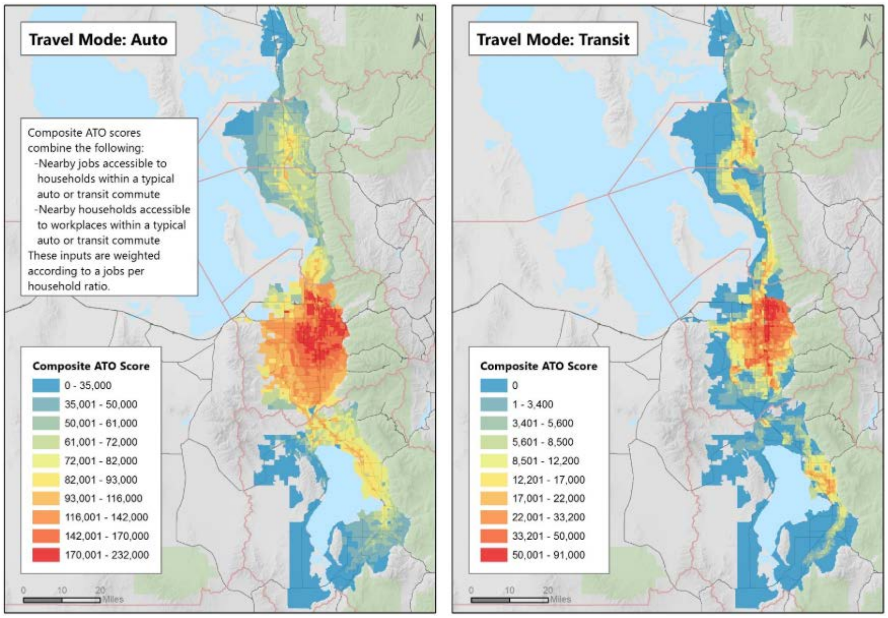

Figure 6. Regional ATO measures describe access to jobs by auto and transit based on travel demand model outputs. Source: WFRC.

SMART LOCATION (NATIONAL)[10]

The U.S. EPA has developed a suite of Smart Location mapping tools to encourage government agencies and others to develop in highly accessible neighborhoods in order to reduce travel emissions and improve public health through active transportation.

[10] More information at https://www.epa.gov/smartgrowth/smart-location-mapping

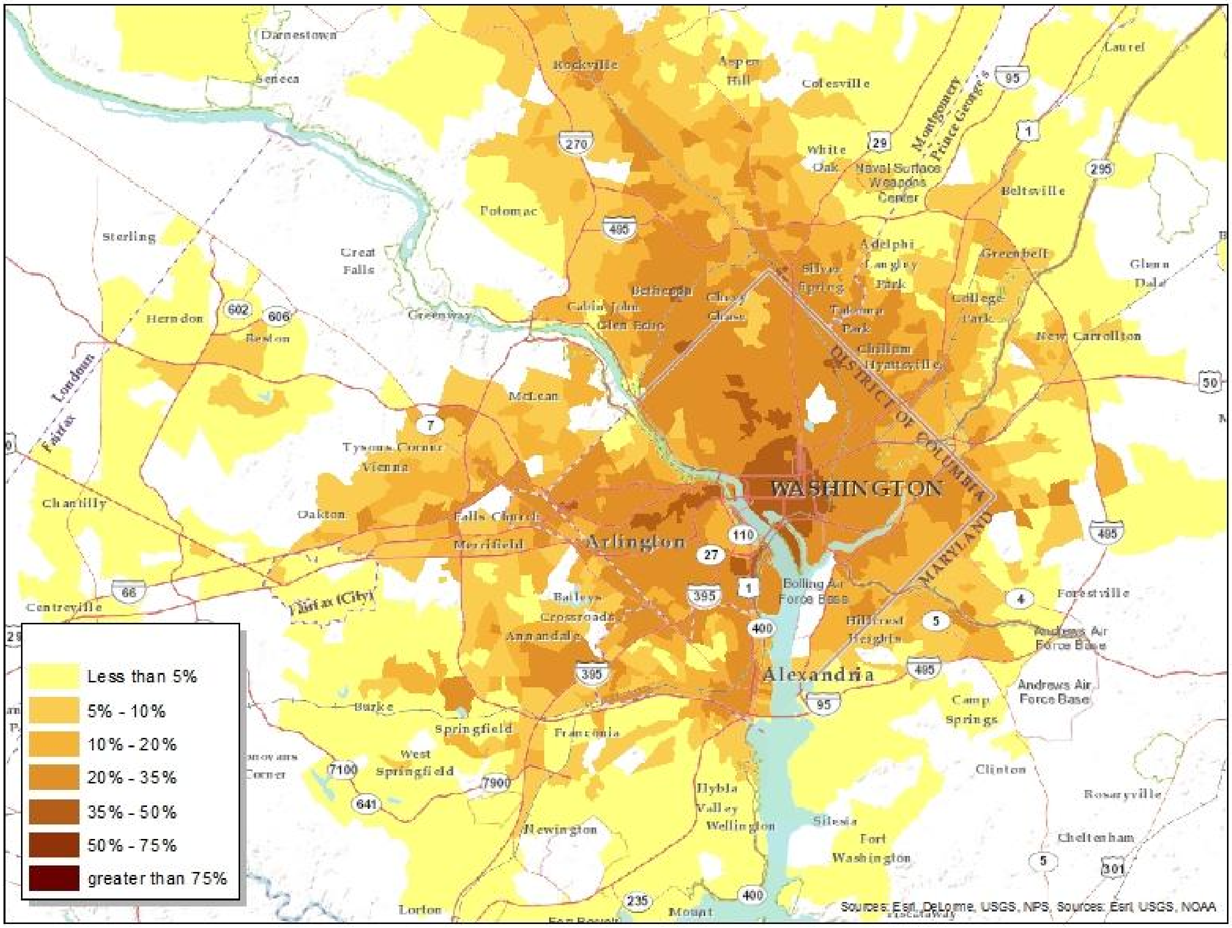

Figure 7. Output from U.S. EPA's Access to Jobs and Workers Via Transit Tool, one of the agency's Smart Location Mapping tools. The map shows the percentage of jobs around the Washington region that are accessible by transit. Source: U.S. EPA.

DEFINING ACCESSIBILITY

So far we have implied that short travel times—from fast travel, proximate destinations or both—equate to good destination access, and that is generally the case. There's more to the story, however. Accessibility is the ease by which we can reach destinations, and there are potentially many factors beyond speed and proximity that could affect "ease." A critical one for active transportation modes is safety and comfort. It might be legal to walk along or across a busy arterial with fast-moving traffic, but if travelers would avoid that route, we cannot use it to determine travel times the way we would with a safer facility. As well, some travelers may avoid a route with a toll on it or a destination where parking is limited or expensive. Transit riders may take a longer trip to avoid a higher fare. Wheelchair users will avoid routes without curb-cuts or flat cross-slopes. Some travelers may be prohibited by income, age or ability from driving at all, and thus have an auto accessibility of zero without another driver.

And when it comes to time, some minutes may count for more than others in terms of "ease." Five minutes of waiting for a bus in the rain will be harder to bear than five minutes sitting on a warm, dry bus.

In short it is possible to imagine a lot of ways to operationalize accessibility and many authors have, producing a rich literature dating to at least the 1950s conceptualizing a host of accessibility metrics (*15*). Unfortunately, however, this literature has made relatively little impact on practice until recently. One problem has been the lack of data, e.g., on location, extent and condition of transportation facilities and on land use locations—issues that still remain to an extent but have improved with the widespread use of navigation apps. The other main barrier to practice has been the sheer multitude of accessibility metrics in various papers and reports. Few practitioners have the time and resources to digest all that material in order to decide how to apply accessibility to their particular problem. This guide employs some of the most common techniques in emerging practices, producing meaningful metrics while relying on data that is either free or inexpensive and analytical methods that do not require extensive training. For those who desire additional nuance in analysis, say, by considering additional transportation network conditions not covered here, this method can serve as a solid base.

CALCULATING AND REPORTING ACCESSIBILITY: THE BASICS

This guide will go into greater detail later, but here is a broad-brush account of how to "do" accessibility analysis.

Accessibility is typically reported as the number of jobs or physical destinations reachable from given starting points, or "cumulative opportunities."

Most simply, destinations reachable via transportation facilities can be summed within travelsheds, or "isoschrones," and indeed we often see accessibility reported as "the number of jobs accessible within 30 minutes" or something similar. However, declaring destinations within 30 minutes to be accessibile and those a minute further away not accessible is arbitrary. Intuition, verified by travelers' reporting, tells us that the value of a destination doesn't go from 100 percent to nothing if it is one second further away but rather declines with time or distance. Therefore, in summing available opportunities, it makes sense to count those that are easily reached more than those that are harder to reach, a technique similar to the gravity model used in travel demand modeling. In accessibility we tend to talk about "decay weighting" to avoid some of the debate about the functional form of gravity weighting in demand models. By decay-weighting opportunities based on travel behavior, we can produce metrics that include all the reasonably available opportunities, rather than excluding those beyond an arbitrary travel time threshold, and we can talk in terms of "the number of jobs accessible," without an arbitrary time cutoff.

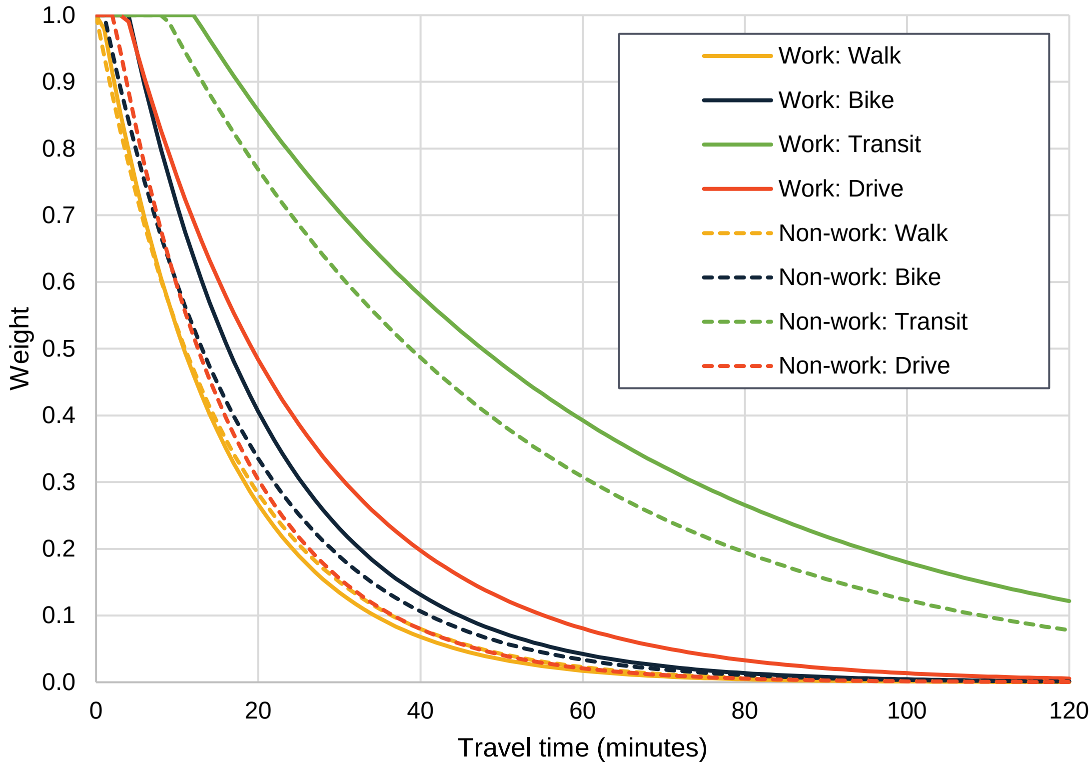

Figure 8. Sample decay functions by trip purpose and mode, based on travel time distributions in the National Household Travel Survey. Weighting a 20-minute trip at 0.5 means that half the surveyed population traveled 20 minutes or longer to reach the destination. Source: SSTI.

Going further, opportunities are not all equally important. For some analyses we may want to consider employment, or jobs in certain employment categories. These we generally sum as the number of jobs accessible. For other analyses we may want to look at non-work destinations, such as schools, food stores, and green spaces. These are often described as "points of interest" or POIs. If we look only at one type of non-work destination, we may report it as we do jobs, e.g., the number of grocery stores that can be reached. Often we want to consider many types of non-work destinations together and normalize accessibility, as the popular Walk Score app does, from 0 to 100.[11]

[11] More information at https://www.walkscore.com/

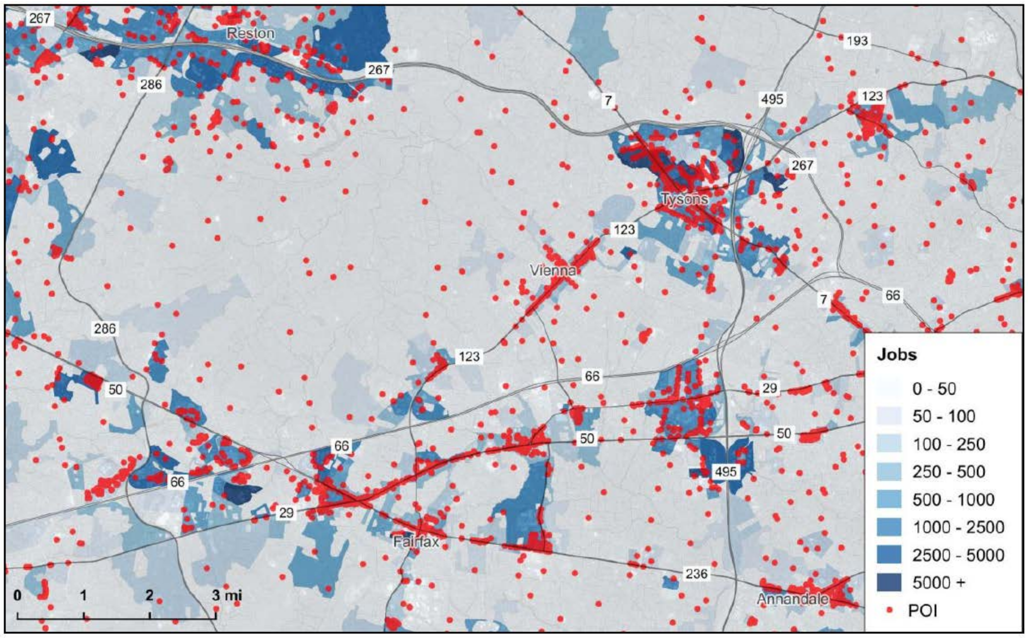

Figure 9. Jobs and non-work destinations (POIs) in Northern Virginia. Source: SSTI.

And while we cannot reasonably take into account every aspect of the transportation facilities or every distinction between land uses, there are some basics we need to include in order to produce valid metrics. These begin with the location and extent of such facilities, as depicted in routable networks in GIS. But we also care about such elements as:

- Operating speed of cars.
- Timetables and stop locations for transit.
- First- and last-mile connections to transit stops (usually by walking).
- Safety conditions on bike and pedestrian facilities that could lead users to avoid particular routes.

Taking all of this into account, we can produce maps that show access to chosen destinations from points or neighborhoods around an area. If we produce a map of these matrices, we might be able to spot problems, such as food deserts or inequities in access to employment. And if we adjust the input data to reflect a change to a transportation facility or to a land use, we can see how accessibility changes as well, and thus judge the efficacy of the potential project.

There is usually another step, however, if we want to use accessibility in decision-making. Rather than trying to judge the merits of a decision by colors on a map, we will usually want some kind of accessibility score for the transportation project or land use. We can do this by summing or averaging the scores for all the neighborhoods in the project area, perhaps weighted by population in each neighborhood. Then we will be able to, for example, compare accessibility impacts of various proposed transportation project or land uses, or develop minimum standards for acceptable accessibility and apply them to real situations.

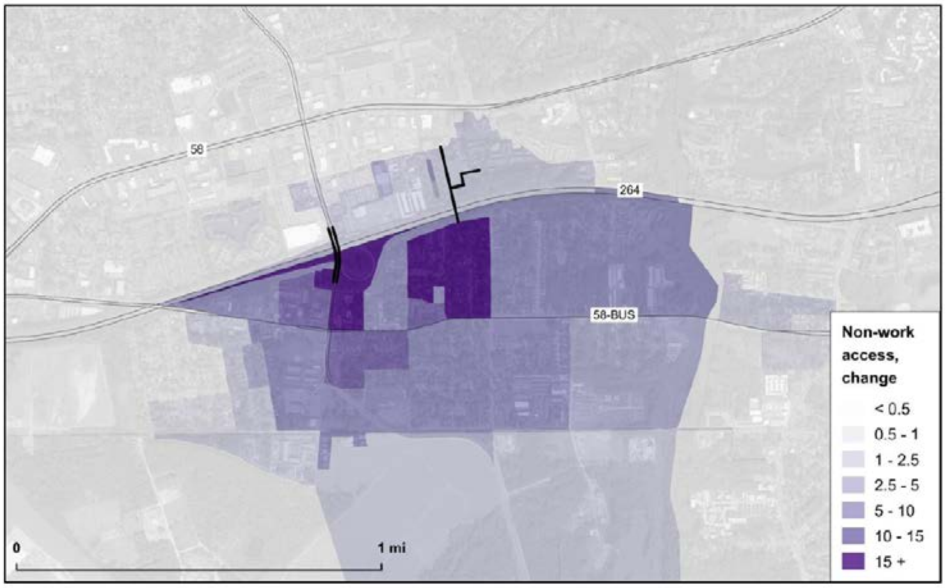

Figure 10. Improvements in accessibility provided by two hypothetical freeway crossings in Virginia Beach, Va. Source: SSTI.

Pedestrian non-work access					Weight (population)	Weighted change
Census blocks with greatest change	Block number	Before	After	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*

Figure 11. Calculating the total and average impact of the Virginia Beach project. (Not all rows shown.) Source: SSTI.

ADVANCED CONCEPTS

The metrics presented in this guide—cumulative-opportunities and decay-weighted metrics—typically fall under the general umbrella of place-based metrics. That is, they describe the opportunities available from a specific location. Person-based metrics, including space-time prisms, can account for individual characteristics like available travel options, travel budgets and fixed anchor points such as work locations, but they are less useful in planning applications. Utility-based metrics, including logsum accessibility, let planners account for individual characteristics and choices, but they typically require more complex travel demand models to estimate and the results, reported in terms of utility, are more abstract.

Even within the realm of place-based metrics, more advanced concepts can be applied. For instance, travel times used to calculate access to opportunities are often based on just one leg of the trip (travel time to jobs during the morning peak period, for instance), but the total travel time associated with each destination could also include the return trip. Another advancement found in accessibility literature is to account for competition among opportunities, often by applying an additional utility factor to opportunities based on their access to individuals (e.g., households or workers).

PULLING IT ALL TOGETHER

While accessibility languished in the ivory tower for many years, today the needed data and computing tools are available to practitioners. In part we can thank the navigation app industry for these advances, but modern computing power and GIS software also plays a role. Practitioners can perform a lot of accessibility analysis armed with only publicly available Census data, common GIS network files, and a standard GIS program. Most users will probably want more, however, and may want to procure data such as locations of stores and observed speeds of vehicles. As well, a tool specifically built for accessibility analysis may be helpful. One of the goals of this guide is to help practitioners decide on the best data and platform for their particular use cases.

This guide, then, will allow practitioners to begin applying accessibility to decision-making. Of course, as with the planes in World War II, having these metrics won't guarantee success. Accessibility metrics alone won't address all of the problems listed at the start of this chapter. It is possible to improve accessibility and still induce more traffic. For example; building a new downtown expressway would likely do exactly that (more on this in the "Concluding Remarks" section). And agencies must respond to policy goals beyond accessibility.

But accessibility metrics will help decision-makers consider the four main personal transportation modes together, at very granular scales, in ways they haven't been able to before. And crucially it brings in land-use proximity as an option for improving outcomes as well.

This guide isn't the end of the story for accessibility. Research and practice will continue to evolve, data and methods will improve, and policy demands around metrics will change. As noted above, accessibility is associated with outcomes such as VMT and modal usage, suggesting that we can use accessibility to forecast those outcomes. We address such forecasting in this guide but expect more development on this front soon.

ACCESSIBILITY IN CONTEXT OF OTHER TOOLS AND MODELS

Transportation and land use decision-making are already informed by a host of rules of thumb, standards, and models. Our opening argument in this chapter is that these have not always served us well, and we cite overuse of LOS as an example. That is not to say that accessibility can or should replace all of these other rules. LOS may have its place as a way to consider localized impacts of transportation or land use changes.

We resist the urge to use the term "models" for accessibility tools. Modeling connotes a simulation or forecast, while our measures of accessibility are direct. That puts them in a different category than transportation demand models. But potential uses of the two overlap; indeed it is possible to calculate accessibility using demand models, and it is possible to use accessibility scores to build predictive models.

Transportation demand models were developed to help metropolitan planners decide where to add capacity, usually highway capacity, as the nation's cities suburbanized. Based on anticipated new land uses that practitioners provide exogenously, the models predict where people will travel, and by which mode and route. In theory they can tell planners where capacity needs to be added to avoid congestion on popular routes.

Accessibility tools, on the other hand, simply measure the quality of access to destinations, either with current conditions or after anticipated changes to land uses or transportation facilities. If access to certain destinations is the policy goal, the tools described in this guide let us measure it directly. It is possible to go further and predict outcomes such as VMT and modal usage as a post-processing step with accessibility scores, but if we want to distribute anticipated trips around the network to determine capacity needs, then we need to resort to a demand model.

Demand models are cumbersome to run, so most agencies are not able to evaluate individual projects, much less various potential designs and alignments of potential projects. Most models rely on coarse geographies and abstract transportation networks that do not represent trip-making well, particularly by walking and biking. And they are not geared toward accessibility as the desired outcome, but rather toward the avoidance of delay – which may not be a problem if destinations are close or if travelers are using a mode other than auto. As well, conventionally used demand models do not address induced traffic from highway expansions.

Accessibility tools can improve practice by shifting the emphasis from delay, whether measured directly as LOS or predicted in a demand model, and by allowing nimble assessment at a granular scale of many possible scenarios at the project, area, or program level. With post-processing steps they can also help forecast some variables of policy concern, and help to capture induced VMT as well.

TRANSPORTATION DATA

Along with data on land uses, data on transportation facilities are a key component of any system or tool for measuring accessibility. In this guide we are concerned with the four main local-regional transportation modes—walk, bike, transit, and auto[12]—and how they are represented with network data that we can use for analysis. Often the networks we use are limited by available data, e.g., whether the location, extent, and condition of sidewalks is known. Other times we may only need particular networks or network attributes for our analysis, and therefore limit the data for practical purposes. This chapter covers the suite of data needed to create networks for the most common types of accessibility analysis, with some workaround suggestions for situations where data is unavailable. It does not cover every potential transportation network-related issue. But advanced users with interesting new data related to networks—say, varying walking conditions related to hillslopes—could build them into the framework we present here.

GENERAL CONSIDERATIONS

When we calculate accessibility, we want to know how easily a traveler can get from one location to another using one or more of our four modal networks. "Ease" is generally, but not always, expressed in terms of travel time. If one household has access to 10,000 jobs within a given radius by a given mode and a second has access to 20,000 jobs, the second could be said to have twice the employment accessibility by that mode. But "ease" isn't solely a function of time; a driver may encounter a toll, for example, which could affect their ease of travel. Travel by walking and biking is particularly sensitive to issues other than travel time. Exposure to risks from traffic hazards, measured as "level of traffic stress," play a key role in assessing the ease of travel along these networks.

All of the modal networks must be able to connect the land uses to each other, and it's often beneficial to look at land use in a fine-grained way compared to what planners are used to seeing in a demand-model environment. To assess walking, biking, and transit accessibility we need to operate at a Census block or even more granular scale—all the way down to tax parcels, potentially. Therefore our networks need a similar level of granularity. The zonal centroid connectors from demand modeling won't suffice; we need very realistic networks that can represent travel times and conditions between small geographies. Often in GIS these networks look like a detailed map with precise

[12] Extensions of the material in this manual could apply accessibility metrics to freight movement, long distance travel and/or other forms of local-regional personal travel.

locations. But not always; with transit, we only care about where the bus or train stops—as well as the walking routes to and from those stops—so we don't need geographically precise representations of transit routes between stops. For active transportation, on the other hand, verisimilitude can be important, and it will be quite useful to have an accurate network based on the location, extent and condition of sidewalks rather than roadway centerlines as a rough proxy.

A useful question to ask when assembling transportation data is how well they will reflect what we want to analyze. If we are only concerned with baseline conditions, the job will be easier, and we can more readily accept data limitations, such as centerlines in place of sidewalks (though even in that case, the centerline approach leaves a lot to be desired, e.g., in places with great distances between roadway crossing points). But if we want to consider before-and-after scenarios, we want to make sure our networks are capturing the effects of whatever treatment is under consideration. Again, using sidewalks as an example, if a project would add sidewalks where they are missing along a busy arterial, we would have to use a workaround to see the effect if we are using roadway centerlines as an indication of walking routes.

Below are some key attributes to consider for each mode.

AUTOMOBILE

Most often used:

- Location and extent of roadways.
- Speed of traffic by segment and time of day.
- Turning movements.
- Directionality.

Advanced applications:

- Tolls.
- Intersection delay.
- Parking cost and availability.[13]

TRANSIT

Most often used:

- Route location, frequency and travel speed by time of day, often derived from General Transit Feed Specification (GTFS).
- First- and last-mile connections, usually by walking or driving.

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[13] While parking is correctly thought of as a transportation feature, it may be difficult to model as a network attribute. Instead, it would most likely be considered a travel impedance associated with particular zones or land uses.

Advanced applications:

- Real-time vehicle departures and arrivals.
- Fares.

BICYCLE

Most often used:

- Location and extent of legally bikeable roadways.
- Speed assignment, often around 10-12 mph, not including intersection and crossing delay.
- Comfort level by link—e.g., bicycle level of service (BLOS) or level of traffic stress (LTS)

Advanced applications:

- Intersection crossing times.

PEDESTRIAN[14]

Most often used:

- Location and extent of legally walkable facilities.
- Speed assignment, often around 2.5 to 3 mph, not including intersection and crossing delay.Comfort level by link—e.g., pedestrian level of service (PLOS) or level of traffic stress .

Advanced applications:

- Intersection crossing times.

NETWORK ELEMENTS

Conducting an accessibility analysis means converting the available transportation data into a routable network made of links, nodes, and sometimes turn movements, and assigning an impedance to each link. Many practitioners will be familiar with routable GIS networks. For accessibility analysis, travel times on these networks are key, and we need to account for impedances—tolls, safety hazards, crossing delays, etc.—travelers will encounter.

[14] Pedestrian access could also include features that affect people with physical disabilities, such as people using wheelchairs, but the available data in most cases makes this not yet possible in practice.

These networks can be simple or complex. Travel demand models, for instance, often use vastly simplified networks representing travel time between traffic analysis zones (TAZs). Such networks are poorly suited for measuring bicycle and pedestrian accessibility, and transit accessibility as well, due to the first- and last-mile walk component. Networks built from GIS mapping data, on the other hand, can incorporate information about every road, transit route, and path, which are then converted into links and nodes to form networks. Aside from those representing one-way streets and transit networks, each link typically has two travel directions associated with it and might have different travel costs associated with each direction. Networks built from available GIS data typically treat each road centerline as a network link, which means bike lanes and sidewalks are considered road attributes rather than individual network links. Therefore, accounting for costs like crossing a busy road might require creating a more detailed pedestrian network.

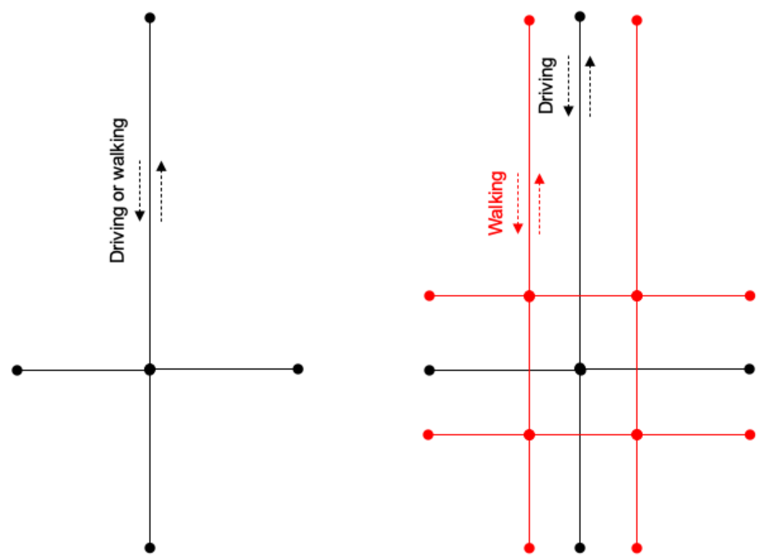

Figure 12. Centerline-based network (left) and centerline plus pedestrian network (right).

Transportation data, both spatial and attributes, may come from a variety of places. Some commercially available accessibility tools provide data, but often the practitioner must supply it. Where desired data is not generally available, e.g., where sidewalk-based networks do not exist, a practitioner may employ it on an ad hoc basis in an immediate project area. For example, if pedestrian facilities are represented by centerlines, it may be useful to draw walking facilities on each side of a street to better represent conditions in the immediate project area. Because walking distances are short, centerline-based networks can be acceptable outside of the immediate area, as the time spent creating more realistic networks would have little effect on metrics.

Different tools and analytic platforms incorporate different data sources and formats for building networks. Some incorporate proprietary data with information like road speeds, while others rely on free and open data sources. Almost all use the common GTFS data format to construct transit networks. Most platforms also let users incorporate their own data in common GIS formats and offer tools for editing the networks after they are incorporated.

CUBE Access, an accessibility analysis tool by Bentley, uses the same data format as the company's popular CUBE modeling software, but lets users edit and manipulate the network data in ArcGIS using a proprietary add-on. Road networks are built from HERE Technologies data, which include observed speeds on every link, and transit networks are built from GTFS data but represented as generalized links describing the average speed and frequency of transit service during various dayparts. Separated bicycle and pedestrian facilities are represented in the networks, while bike lanes and sidewalks are represented as road attributes. This information might not be as reliable as local inventories.

Conveyal is an online accessibility analysis platform that incorporates road network data from OpenStreetMap (OSM) and transit network from GTFS data. The quality of OSM data varies by location depending on how active local users are, but it sometimes offers greater detail than other proprietary data. Users can edit the networks in the platform using advanced transit modification tools and simpler road modification tools. They can also upload network data in OSM, PBF or GTFS format, letting them modify the networks using other common editing tools.

Other platforms are discussed in more detail in the section describing methods and tools.

NETWORK IMPEDANCES

The most common link attribute used to measure accessibility is travel speed. Ultimately, however, any of the network impedances described above, must be translated into a travel time cost for each link (also known as "generalized cost" in travel modeling). For instance, a quarter-mile road segment approaching an intersection might have an average speed of 10 mph, which means it takes 1.5 minutes to travel the segment and clear the intersection, after accounting for typical intersection delay. The cost of walking along that link might include five minutes of walking at 3 mph, another two minutes to cross the intersection, and any other perceived costs associated with nearby traffic or insufficient sidewalks. The perceived costs of walking and biking can be captured using a measure like level of traffic stress (LTS) described below.

In travel demand modeling, the monetary and time costs of travel are often translated into a generalized cost based on assumptions about the value of time, e.g., median wage rates. A $5 toll bridge, for instance, might incur an extra 20-minute time cost in accessibility analysis for people earning a $15 hourly wage. This approach requires careful thought, however, so as not to ignore the real tradeoffs between time and money. For instance, a congestion charge adds a monetary cost, but also improves accessibility by keeping roads moving during peak periods, which might be of more value to travelers.

WALKING AND BIKING SPEEDS

Average walking speeds are typically around 3.0 mph, according to several studies of pedestrian crossing behavior, with speeds as low as 2.4 mph for older pedestrians (*16–18*). Most current design guidelines recommend baseline walking speeds of 2.4 to 2.7 mph. These observed speeds do not include delay caused by walking in urban environments. Average cycling speeds for typical commute-type behavior are around 10-12 mph, but average travel speeds in urban environments can be as low as 5-9 mph (*19–23*). Baseline speeds on the higher end of these ranges should be used when the analysis includes detailed impedances for intersection and crossing delay. Lower speeds can be used to err on the conservative side of comfort and ability and to account for those impedances.

LEVEL OF TRAFFIC STRESS (LTS)

Transportation practice has revolved around the level of service (LOS) concept for many years. Derived mainly for planning auto facilities, but sometimes also applied to other modes, LOS is concerned with whether a facility has enough capacity to maintain travel flows. It uses familiar letter grades that decrease as delay increases.

While auto-style LOS is sometimes applied to active transportation facilities–say, when a popular national park must plan to handle crowds of tourists around an attraction–most often this metric is irrelevant to active transportation access to destinations. Concepts like bicycle LTS or the related bicycle compatibility index (BCI) focus more on the effects of traffic and road design on cyclist comfort. There is similar research looking at factors affecting pedestrian comfort, but no widely accepted standards. Both the Accessibility Observatory (*24, 25*) and PeopleForBikes (*26*) have used the LTS concept in accessibility analysis, with some minor variations. The following tables show how to apply this approach for both cycling and walking.

The baseline LTS values in Table 1 assume a segment does not have dedicated bicycle or pedestrian facilities, meaning that a cyclist must ride with traffic and a pedestrian must use the available shoulder or right of way.[15] The improved values shown in parentheses apply if the minimum acceptable bike facility or sidewalk is provided (Table 2). The framework proposed here adds two LTS ratings: LTS 1+ is reserved mainly for separate facilities and LTS 4- is reserved for high-speed roads that require separate facilities. This differentiation is helpful in applying impedance factors to network links, described below.

[15] This approach does not account for accessibility via wheelchair. For such an analysis, most links without dedicated facilities would receive a 4-.

Table 1. Level of traffic stress

Speed	Separate facilities	Local / Res.	Other		
		2 lanes	2 lanes	4 lanes	6+ lanes
0-25 mph	1+	1 (1+)	2 (1)	3 (2)	4 (3)
30 mph	N/A	2 (1)	3 (2)	4 (3)	4 (3)
35 mph	N/A	3 (2)	4 (3)	4 (3)	4 (3)
40+ mph	N/A	4	4-	4-	4-

( ) = LTS with acceptable bicycle or pedestrian facility; see Table 2.

Table 2. Minimum acceptable bike facilities

Speed	2 lanes	4+ lanes
0-20 mph	1	3
25 mph	2	4
30 mph	3	5
35 mph	5	6
40+ mph	6	6

1. Low-speed shared street.
2. Shared street ≥19 ft (≥27 with parking on both sides).
3. Bike lane ≥4-5 ft (≥13 ft with parking).
4. Buffered bike lane ≥6 ft, including marked buffer and paved gutter (≥15 ft with parking).
5. Buffered bike lane ≥6 ft (no parking).
6. Separate facility.

It is common in accessibility analysis and other uses of the LTS concept to only allow trip-making on low-stress facilities (LTS 1 or 2). In other words, we impose a 100 percent impedance on facilities rated 3 or 4. This might be valid for many users, but it can ignore existing connections that are critical in accessibility analysis. Consider, for instance, a bus stop near a large residential neighborhood that requires a short walk along an unpaved strip of land. While this is a critical problem worth addressing, it is inaccurate to say the neighborhood has no transit access. Doing so could fail to capture the benefits of additional bus service or sidewalk improvements outside of the unpaved area.

Analysts could therefore apply scaled impedance factors corresponding with each LTS value (Table 3). Based on the factors shown, for example, walking or cycling along an

LTS 4 facility is modeled at 60 percent of the baseline speeds (typically in the range of 2.5 to 3 mph for walking and around 10 to 12 mph for cycling). In other words, a 6-minute walk translates to a perceived 10-minute walk (1.7 times longer). Put differently, the cost of a 6-minute walk at LTS 4 is equivalent to that of a 10-minute walk at LTS 1. Our shortest-path accessibility analysis, then, may consider a route that is longer in distance as preferable to a shorter one with greater traffic stress.

Table 3. LTS values with corresponding and speed and time factors.

LTS equivalent	Speed factor	Time factor
LTS 1+	1.1	0.9
LTS 1	1.0	1.0
LTS 2	0.9	1.1
LTS 3	0.8	1.3
LTS 4	0.6	1.7
LTS 4-	0.4	2.5

More input and research may change the calibration of these factors, but we already have supporting research to guide these decisions. We know, for instance, that about half of cyclists identify as "interested but concerned," while about 10 to 15 percent are confident riding on streets (*27*)—knowledge that could inform relative impedance factors. There is also a body of research aimed at understanding the relative perceived walking times under different built environment conditions (*28*, *29*). Our current approach is more policy-driven, based mainly on work developing Virginia's project prioritization process, SMART SCALE. Notably, improvements along poorly rated roads will have a larger accessibility impact. For instance, a new facility on an LTS 4 road translates to a 50 percent reduction in traffic stress (from 0.4 to 0.6), whereas a facility on an LTS 1 road merits only a 10 percent reduction. Similarly, lowering faster traffic speeds to 35 mph translates to a 100 percent stress reduction in most cases, which corresponds roughly with the relative risk of being killed in a collision (*30*, *31*).

LAND USE DATA

Along with transportation, the other key dataset we need in order to calculate accessibility metrics is land use. In some cases, land use data may be simple and easy to obtain. For example, if we want to measure household access to train stations in a city, we can download U.S. Census population data to go with the station locations we presumably have on hand. On the other hand, we may need to procure certain data, such as retail store locations or locations of particular kinds of households, if those are of interest.

GENERAL CONSIDERATIONS

When decision-makers consider accessibility, say to choose among transportation-project proposals, they very often look first at access to employment for several reasons: 1) the data are relatively easy to obtain and use, 2) jobs are often viewed as a useful proxy for other important destinations and economic centers, and 3) transportation decision-making is often focused on level of service at "peak hours," when 9-to-5 workers are commuting. In this case, the Census provides useful data about the location of jobs, which can also be broken down by income level, job type, and other characteristics.

However, it is worth noting that most travel is not for work (Figure 13), so if we're interested in a full picture of destination access, we need to consider non-work destinations. For example, we might want to examine household access to certain core services, such as food stores and healthcare facilities. And if we want to predict VMT and mode choice outcomes, we need to look at a full range of typical destinations. Information about where many of these destinations are located can be inferred from free jobs data using industry codes, but analysts will frequently want more specific information about "points of interest" (POIs), which is usually proprietary data that comes with a fee. Destinations like parks typically do not have jobs associated with them, and others, such as multiple stores in a strip mall, will be hard to distinguish from jobs data.

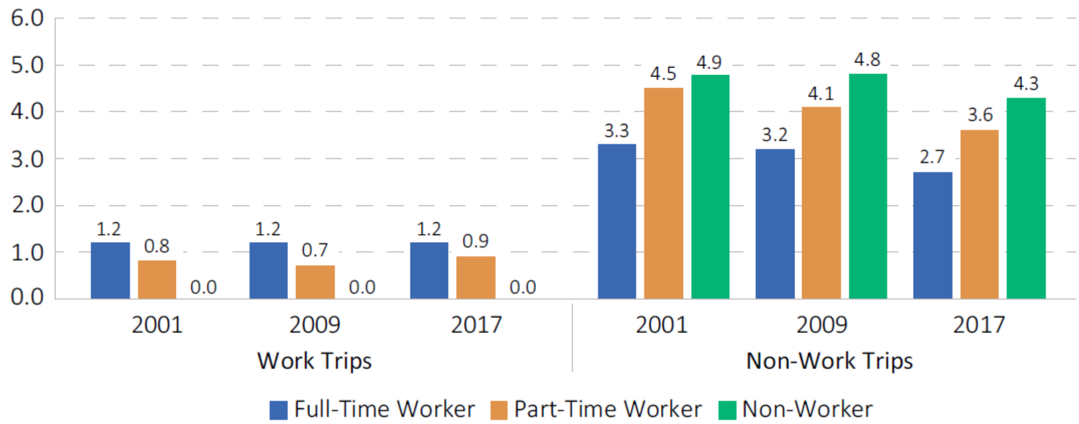

Figure 13. Daily weekday trip rates, adults 23-65. Source: FHWA.

Some tools come pre-loaded with certain land use data. CUBE Access, for example, comes with population and employment data from the Census and proprietary POIs. Conveyal comes with the same employment data, which are redistributed as points and lets users add any other available data.

ANALYSIS ZONES

In some cases, we may consider land uses as points, e.g., if we look at access from individual homes to a nearby transit station. Most often, though, we will be dealing with aggregated land uses, and our analysis will be based on travel time matrix from origin zones to destination zones. Important considerations in choosing analysis zones include:

- The availability of data.
- The resolution of the analysis.
- Computational requirements and capabilities.

The availability of data—particularly Census data—may dictate the size of analysis zones. Certain Census jobs data, for instance, can be obtained at the block level, but other household-level data, such as income, may only be available for block groups, which are larger both in geography and population.

Aggregating data to larger zones, which is common in travel demand modeling, can be an issue in accessibility analysis—particularly when looking at walking and biking, which involve short trips. Our origin-destination matrices will be considering travel times to and from centroids of each zone, so block groups, for instance, may be too large to reflect important local trip-making.

Finally, while small zones such as parcels can produce detailed analysis, they can also drastically increase the computational needs. As discussed later in this document, accessibility analysis considers travel from every zone to every other zone in the system, so the number of calculations increases exponentially with the number of zones.

A good rule of thumb is to use Census blocks for walking and biking analyses, which often cover much smaller areas, and block groups for driving analyses, which are often more regionally focused. Transit analyses, however, can pose some challenges because they are often regionally focused but also require a more granular understanding of walking access around transit stops. One solution is to use smaller zones like Census blocks in the area of interest (i.e., near transit stops and where accessibility metrics will be reported) and larger zones like block groups in more outlying areas.

Census geographies can present another issue—irregular zone sizes and shapes, especially in less dense areas, which can give rise to inconsistencies in travel-time calculation from zone to zone. This can be handled by reallocating land uses to uniform grid cells, as in the Conveyal platform. Given sufficient computing power and efficient routing algorithms, this approach addresses most of the potential issues described above.

The following sections describe data on residential, employment and non-work destinations in more detail.

RESIDENTIAL LAND USES

Residential land use data (e.g., persons and households) are generally most useful for filtering and cross tabulating the results of an accessibility analysis. For example, we might want to estimate the average household accessibility to jobs in region. In this case we would calculate employment access from each zone, and then apply relevant populations to those zones in order to arrive at an average for all households. But residential data can also be used to measure access to households, population, and workforce from employment or activity centers.

U.S. CENSUS DATA

Data from the Census is free, consistent across the country, easy to access, and familiar to most practitioners. The Census Bureau provides updated data each year at the Census block-group level on population and household characteristics, as part of the American Community Survey (ACS) program.[16] Estimates of population, housing units, and some individual characteristics like age and race are also available at the block-level every 10 years. Smaller geographies tend to have larger margins of error. Therefore, when choosing a data source, there are tradeoffs between spatial resolution, level of

[16] More information at https://www.census.gov/programs-surveys/acs

detail, and data accuracy. A breakdown of the most recent available data is shown in Table 4.

Table 4. Availability of Census data by product and geography.

Attribute	Block	Block group
Population	2010	2010, ACS5
Housing units	2010	2010, ACS5
Sex and age	2010	2010, ACS5
Race	2010	2010, ACS5
Income	*N/A*	ACS5

OTHER SOURCES OF DATA

As just noted, there are times when we want to go beyond what the Census offers. Using public data, tax parcels may help for very granular analyses, and land-use plan maps may be a good source of data for future-year accessibility. It's possible to imagine useful analysis of access to particular health services by a known, agency-served population; access to polling places by citizens on voter rolls; or access to schools by households with enrolled students.

Private sources may also be helpful. A company may want to evaluate access to a new office building by its existing workforce, for example. And many vendors can provide addresses of particular demographic groups of interest to analysts. Any of these can be accommodated in the same way Census data is, usually aggregated into Census geographies or grid cells as origins or destinations.

EMPLOYMENT DATA

Jobs are the most common opportunity data set used in accessibility analysis. The locations of jobs are usually based on common employment datasets.

U.S. CENSUS DATA

The Census Bureau also provides two sources of information regarding jobs. The first is its Census Transportation Planning Products (CTPP)[17], supported by AASHTO, which reports the location of jobs based on commute flow information from the ACS. These data describe worker characteristics including earnings, industry, age, and race. The

[17] More information at https://ctpp.transportation.org/

most recent, 2016 product includes information for tracts and relatively small traffic analysis zones (TAZs), but TAZs are reportedly being discontinued in favor of block groups.

The other commonly used Census jobs data come from the Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES)[18]. These data are available at the block level for each year since 2002 in most states, with some isolated exceptions, and describe the total number of jobs by NAICS sector, along with workers' age and earnings. There is a typical lag of two or three years in the release of data.

LODES is typically preferred over the CTTP because of its high geographic resolution and because it is frequently updated using extensive administrative records spanning most employers. There are limitations, however. For instance, it misses self-employed and informal workers, along with military employees and U.S. postal workers (*32*).

OTHER SOURCES OF DATA

As with residential data, we may want to go beyond what the Census Bureau offers. Locally produced future employment projections, or future land-use mapping with estimated job numbers, may be needed to assess future accessibility. Proprietary job-projection data can be purchased commercially as well.

NON-WORK LAND USES

Non-work land uses—typically represented as POIs—are of considerable policy interest. We may care about people's access to particular services, for example, when planning new land uses or transportation facilities. We may also want to estimate VMT or modal usage impacts of some prospective change to the built environment; because the bulk of personal travel is for non-work purposes, we must take access to POIs into account. However, despite their importance, POIs are more difficult to capture, as there is no nationwide, publicly available source of data, as there is for residential and employment uses.

POI data can be accessed via an application programming interface (API) from sources like Google Maps, Foursquare and Yelp, but these are generally limited by some combination of fees, query limits or restrictions on allowed uses. POI data are also commercially available from providers like HERE Technologies, InfoUSA, SafeGraph and Factual.

If procuring proprietary data is not possible, there are at least several other options, though the data quality will likely suffer:

[18] More information at https://lehd.ces.census.gov/data/lodes/LODES7/LODESTechDoc7.0.pdf

- Land uses can be inferred from the LODES employment data based on NAICS codes. This requires some rules for converting clusters of jobs into POIs—for example, some number of retail jobs translates into a store—and it may not let users easily distinguish between workers that provide a public-facing service and those in a back office. Some land uses of interest, such as parks, will not necessarily be indicated by employment.
- Free and crowd-sourced POI databases (including OpenStreetMap) may be an option, but these tend to be less reliable than commercial data (*33*, *34*), and their condition can vary by location so a quality assurance check might prove valuable.
- Local zoning, tax-parcel, or other locally compiled data could be used to indicate POIs. Local data will likely be inconsistent across municipal boundaries, and it may not make some key distinctions, such as whether a parcel zoned as a commercial use actually houses a functional, public-facing business.

That said, there are times when public data are superior to those proprietary POIs. For example, proprietary POIs may not distinguish between types of health care providers, and if the desire is to calculate access to public clinics, the list of those clinics would be the correct POIs to use.

METHODS AND TOOLS

Measuring accessibility from a single point is generally simple and straightforward. This accessibility can be visualized as a travelshed map, or isochrone, and reported as the number of destinations within that travelshed. Applying decay weights to destinations adds only a little complexity.

Developing accessibility metrics across an entire region or study area, however, takes more effort. It typically requires three basic steps:

1. Estimating travel times, typically between each zone in a region.
2. Calculating accessibility values for each zone based on land use data.
3. Summarizing accessibility values for projects and scenarios.

The first step in this process, estimating travel times, is typically the most complex and resource intensive. Transportation agencies often rely on travel demand models to produce travel time matrices for each pair of zones (called "skims"). Researchers and accessibility analysts, however, leverage many simpler routing tools such as OpenTripPlanner and Google API. These tools all require underlying transportation network data, including travel times or generalized costs for each link, as inputs. In practical applications like transportation project evaluations, users must also be able to modify the transportation networks to reflect different scenarios and potential transportation improvements, which generally rules out approaches that rely on APIs.

The second step in this process, calculating accessibility values, requires land use data (e.g., jobs) and defined accessibility metrics (e.g., jobs within 30 minutes or decay-weighted jobs). Using the travel times from step one, appropriate accessibility metrics can be defined for each origin zone. Again, users will probably need to be able to modify the underlying land use data—for instance, to develop land use scenarios or to add or characterize points of interest. In most cases, this is a simple GIS exercise.

The third step in this process, summarizing accessibility values, requires decisions about the appropriate units of analysis and how the resulting metrics will be used. An appropriate metric for tracking and benchmarking might be average household accessibility, for instance, while the total accessibility across all households within a given buffer area might be a better evaluation metric for project impacts.

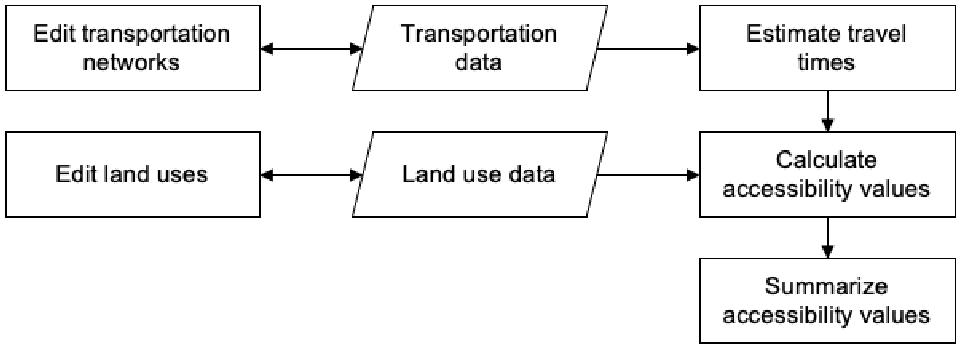

Figure 14. Basic requirements for calculating accessibility in decision-making applications.

The number and variety of tools and platforms for conducting accessibility analysis is growing. Some are simple routing tools, while others are designed to handle each of the steps described above with preloaded data.

REPORTING

Before choosing a tool for calculating accessibility, it is important to know how it will be reported and used. Some tools simply calculate travel times—leaving the remaining steps to the analyst—while others produce isochrones, cumulative metrics, time-weighted metrics, or other accessibility indices. The most commonly reported metrics at the zone level (aka, placed-based metrics) are cumulative opportunity metrics and weighted cumulative opportunity metrics (aka, gravity-based). The two are closely related, with the only difference being the weighting function.

CUMULATIVE VERSUS WEIGHTED METRICS

Cumulative opportunity metrics describe the number of destinations or opportunities within a given travel time (e.g., jobs within 30 minutes). These are easy to report and interpret, but the arbitrary cutoff makes the metrics less accurate in decision-making applications. For instance, the benefits of a major transportation investment might not be captured because a major employment center is 31 minutes away, instead of 29 minutes. These cumulative metrics incorporate a simple weighting function; jobs within 30 minutes receive 100% weight and jobs farther receive 0% weight.

A common solution is to assign a weight to each opportunity based on a travel-time decay function that reflects observed behavior from a travel survey (*35*). Exponential decay functions derived from the National Household Travel Survey (NHTS) are shown for commute trips in Figure 15 and for non-work trips in Figure 16.[19] For instance, for a mode and trip purpose where 50% of travel times are longer than 20 minutes, the weight (or utility) of a job 20 minutes away is 0.5. The final reported metric is the

[19] The underlying data and decay functions are reported in the appendix.

weighted sum of opportunities. Such a metric can be somewhat more difficult to explain and interpret, but it can be described in many settings using shorthand like "the number of jobs within typical commute times" or simply "the number of jobs accessible."

Decay-weighted metrics can be calculated precisely by applying the corresponding weight for each zone based on its travel time. However, approximate decay-weighted metrics can also be derived from incremental cumulative opportunity metrics, by time bins. For instance, jobs within 10 minutes can be assigned an average weight of 0.95, jobs between 10 and 20 minutes can be assigned 0.60, and so on.

Separate decay functions can be employed for different regions or population groups, in order to improve accuracy. But there are good reasons to use more generalized functions in decision-making applications. For instance, using different functions for a compact region and a spread-out region will cause the more spread-out region to appear relatively more accessible than it is (*35*). The same could be said of decay functions for different modes. Transit trips, for instance, tend to be longer than those on other modes. Using the separate modal decay functions therefore makes transit appear relatively accessible, compared to other modes. Decisions on the best decay functions are up to policymakers and analysts.

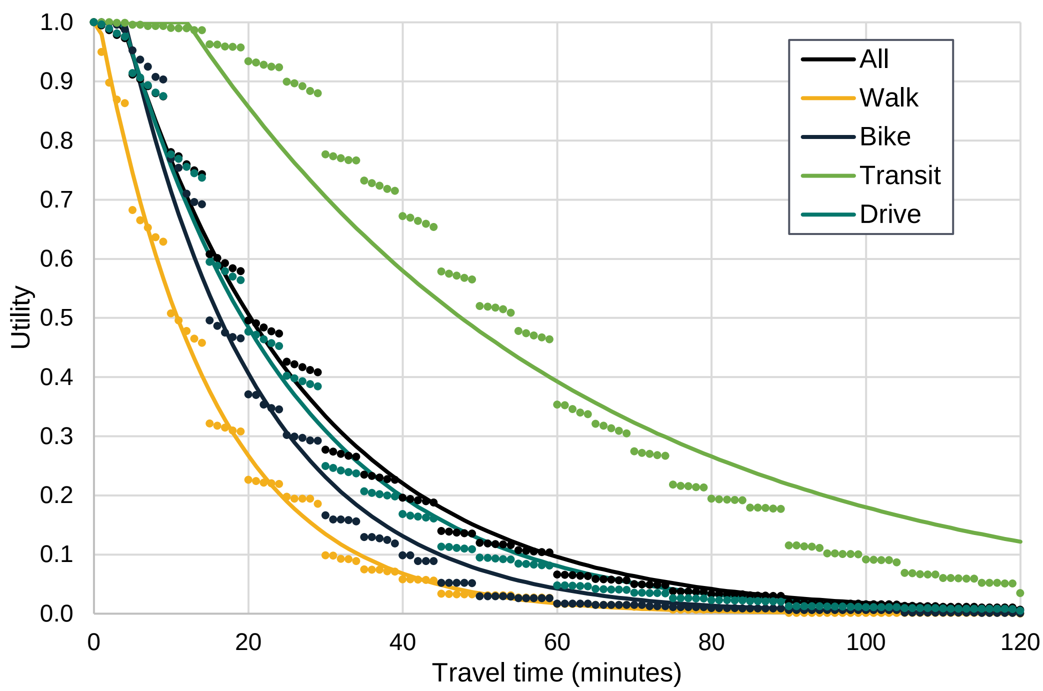

Figure 15. Exponential decay functions for home-based work trips from the 2017 NHTS (raw observations shown as points).

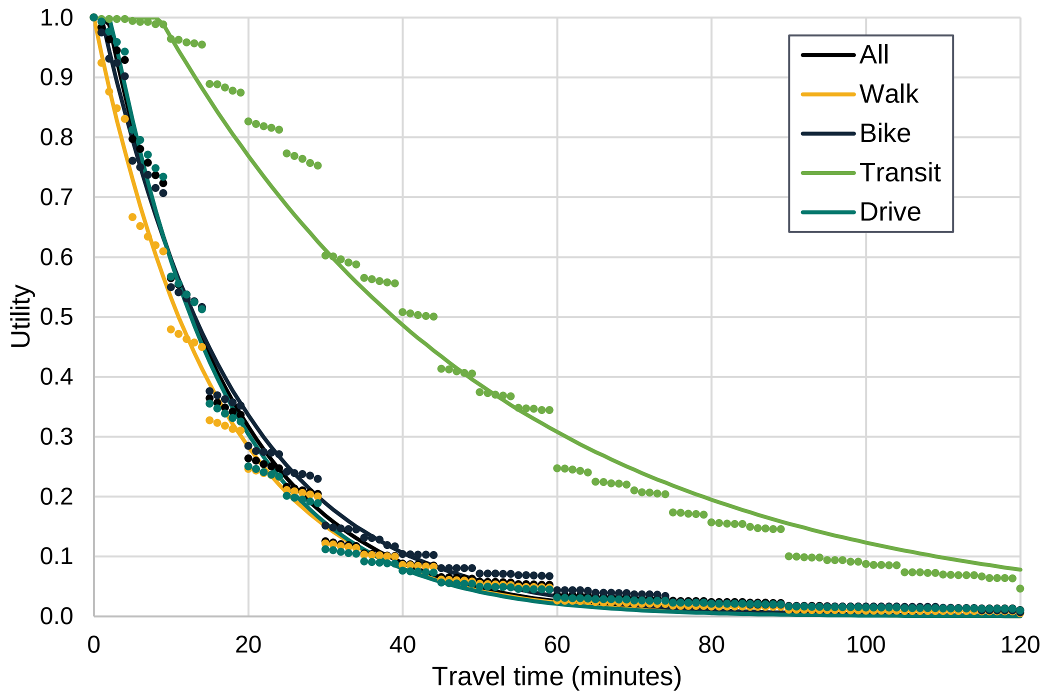

Figure 16. Exponential decay functions for home-based non-work trips from the 2017 NHTS (raw observations shown as points).

NON-WORK ACCESSIBILITY

Measuring access to jobs using the methods described above is relatively straightforward, but measuring access to other non-work destinations is more complicated—mainly because different types of destinations usually have different importance. For instance, a transportation investment that improves access to a school or hospital might be more important than one that improves access to a small specialty store. Policymakers must therefore decide on relative weights for different kinds of opportunities and report accessibility metrics separately for each or combine them into a non-work accessibility index.

There is as of yet no widely accepted index, in large part because, as noted, there is no standard public POI dataset. However, there's a long track record of this practice that comes not from transportation and land use practice or from academic research, but from the real estate industry. Walk Score,[20] owned by the real estate brokerage Redfin, considers pedestrian access to a range of POIs and assigns a score from 0 to 100.

The approach used in Virginia's SMART SCALEis shown in Table 5. Non-work destinations are divided into nine categories, each with equal weight. Each category has a maximum number of destinations, based on observed values from around the state,

[20]More information at https://www.walkscore.com/

that count toward the final score, which then translates into a certain number of points per destination. Destinations can earn partial points based on the non-work decay function and the final score is a value between 0 and 100.

Table 5. Example non-work accessibility score based on Virginia's SMART SCALE.

Destination type	Weight (points)	Maximum destinations	Points per destination
Banks and ATMs	11.1	15	0.74
Education	11.1	2	5.60
Entertainment (e.g., theaters, museums and stadiums)	11.1	2	5.60
Food and drink (bars and restaurants)	11.1	45	0.25
Grocery	11.1	3	3.70
Health (medical services and pharmacies)	11.1	3	3.70
Public services (e.g., libraries, post offices, police stations, and government buildings)	11.1	3	3.70
Recreation	11.1	3	3.70
Shopping	11.1	33	0.34

An emerging best practice in accessibility analysis is to consider access to jobs by driving or transit as a regional indicator and access to non-work destinations by walking or biking as a local indicator (Figure 17). There are several reasons behind this thinking. First, jobs are commonly viewed as a reasonable proxy for regional land uses and activity centers. Therefore, a person's access to jobs by transit, for instance, describes not just their ability to reach jobs, but also their ability to reach opportunities and services more generally. Second, access to non-work destinations is commonly viewed as a highly localized issue. Most drivers, for instance, have reasonable access to daily needs like schools, grocery stores, medical offices, and recreational opportunities throughout their region, but good access by walking or biking is usually limited to those in a handful of neighborhoods.

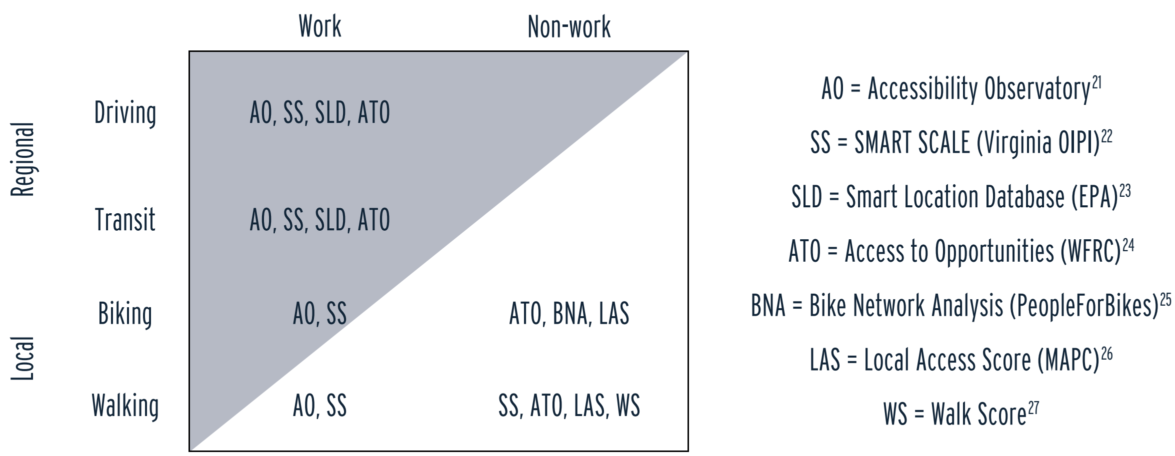

Figure 17. Common accessibility measures by mode and destination type.

SUMMARIZING ACCESSIBILITY

While it can be tempting to measure and report many accessibility metrics—i.e., access to jobs and non-work destinations by all modes—it is important to summarize accessibility in a way that aligns with broad policy goals. For instance, major highway improvements are likely to increase access to jobs by a considerable margin for many households across a region, yet driving access already tends to be much higher compared to transit, biking, and walking access, sometimes by orders of magnitude. In contrast, a project that improves access to jobs by transit in an area with good walking access means that someone is more likely to be able to meet all their daily needs by any mode. This could also translate into less traffic or lower VMT, stronger local economies, and more equitable outcomes. Therefore, a question for policymakers is how to weight different modes—or possibly look at modal scores in other combinations such as ratios—in performance measurement and project evaluation.

Summarizing accessibility across a region or project area also requires a unit of analysis, such as population or households. In other words, after calculating accessibility values for each analysis zone, the area-wide accessibility is reported as the population- or household-weighted average or sum. For individual projects, this also requires a definition of the project area, which should include all or most of the affected population. The unit of analysis also presents an opportunity for equity considerations—e.g., evaluating accessibility impacts across low-income or non-white households.

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[21] More information at http://access.umn.edu/research/america/
[22] More information at http://smartscale.org/
[23] More information at https://www.epa.gov/smartgrowth/smart-location-mapping
[24] More information at https://wfrc.org/maps-data/access-to-opportunities/
[25] More information at https://bna.peopleforbikes.org/
[26] More information at http://localaccess.mapc.org/
[27] More information at https://www.walkscore.com/

PLATFORMS

This section describes commonly available tools for accessibility analysis and considerations for choosing the appropriate tool. The choice depends largely on staff capacity and other available resources, including budget. The four major tools described here offer great functionality and some include all the required data, while others listed below typically require a dedicated analyst to build the necessary capability and pull together any available data.

CUBE ACCESS[28]

CUBE Access by Bentley (formerly Sugar Access by Citilabs) comes fully loaded with all the required data to run accessibility analyses using an ArcMap add-on. Routable auto and active transportation networks and POIs from HERE Technologies, GTFS (converted to a CUBE network), and Census LODES and population data are included with a software license. Data can be manipulated locally in ArcMap but accessibility calculations run on cloud-based servers, letting users run multiple scenarios quickly and simultaneously. Networks are pre-built based on the available HERE and GTFS data. Users can edit networks and network attributes using custom tools within ArcMap or incorporate their own network data in CUBE format.

CONVEYAL[29]

Conveyal is a web-based accessibility analysis platform that incorporates LODES data and network data from OpenStreetMap and GTFS, but no proprietary data sources. Users can upload any available land use data, GTFS data, or road networks in OSM.PBF format. Networks and network attributes can be edited directly in the Conveyal Analysis online platform or using other tools such as JOSM, prior to upload. The platform was originally conceived mainly for transit analysis, so the built-in tools for editing transit networks are more advanced than those for road and active transportation networks.

ACCESSIBILITY TOOLBOX / ARCGIS NETWORK ANALYST[30]

The Accessibility Toolbox for R and ArcGIS was developed by Christopher D. Higgins at the University of Toronto and leverages ArcGIS Network Analyst to produce cumulative and weighted accessibility metrics. The tool runs locally in ArcGIS, so its computing power can be limited, but it allows users to work with familiar data formats such as Esri shapefiles, feature classes, and network datasets.

[28] More information at https://www.bentley.com/en/products/brands/cube
[29] More information at https://www.conveyal.com/
[30] More information at https://github.com/higgicd/Accessibility_Toolbox

TRANSCAD (VDOT MODEL)[31]

The Virginia Department of Transportation (VDOT) recently began using a custom-built accessibility analysis tool developed by Caliper to run in TransCAD. The tool incorporates point of interest and network data from HERE Technologies, transit networks based on GTFS, and land use forecasts from VDOT. Network editing and scenario analysis is all done locally in TransCAD, so computing power can be limited, but scenarios can be run sequentially in batches.

Table 6. Comprehensive accessibility analysis platforms.

	CUBE Access	Conveyal	Accessibility Toolbox	TransCAD (VDOT model)
Platform	ArcMap	Standalone	ArcMap + Network Analyst	Standalone
Default data sources				
Roads	HERE	OpenStreetMap	N/A	HERE*
Transit	GTFS	GTFS	N/A	GTFS
Jobs	LODES	LODES	N/A	LODES / forecast
Points of interest	HERE	N/A	N/A	HERE*
Input data format	Cube network (.gdb)	Roads: osm.pbf Transit: GTFS	Esri network dataset	Caliper network (.dbd)
Network editing	ArcMap extension	Conveyal Analysis (online)	ArcMap (pre- build)	TransCAD
Analysis	Cloud-based	Cloud-based	Local	Local
O-D matrix	No	No	No	Yes
Isochrones	No	Yes	No	No
Cumulative metrics	Yes	Yes	Yes	No
Decay-weighted metrics	Yes	Yes	Yes	Yes
Accessibility index	Yes	No	No	Yes

* HERE data was purchased separately for use in the VDOT model.

[31] More information at https://www.caliper.com/tcovu.htm

USEFUL GIS-BASED TOOLS

Other tools for calculating shortest paths, origin-destination matrices, and isochrones—key steps in accessibility analysis—are available for use in both the ArcMap and QGIS desktop applications. Network Analyst, the ArcMap version, uses ESRI network datasets to model transportation data. As indicated above, ESRI network datasets can include transit data in GTFS format. The QGIS plug-in, QNEAT3, operates in a similar manner to network analyst, utilizing the QGIS LineString vector data format for transportation data. Both tools allow the user to edit transportation networks. In the case of Network Analyst, this would be done prior to building the network, or requires a network rebuild after edits are made.

OTHER ROUTING ALGORITHMS

The intrepid practitioner can assemble their own tools for accessibility analysis on platforms such as Python, R, or Java. These modules include OpenTripPlanner, dodgr, osrmr, igraph, gtfsrouter, tidytransit, cppRouting, stplanr, Pandana, UrbanAccess, peartree, and Networkx, among others. These are maintained to varying degrees, so some discretion on the part of the user may be required.

A number of services can produce O-D matrices, route optimization, or service area isochrones using Application Programming Interfaces (APIs) that scrape online data, but do not let users easily modify networks for project evaluation. These services include Mapbox APIs, GraphHopper API, and Google Maps API.

EXAMPLE ANALYSES

Accessibility analysis can be used for many purposes, but the methods involved are similar. For example, if we know how to calculate access to jobs or schools by one mode, we can typically extend the principles to other modes and destinations. The examples here provide the reader with a solid footing on which to build their analyses, whether the questions to be answered are exactly the same as those shown or not. They employ the data and tools described in previous chapters.

The following examples are based on a hypothetical case study using real-world data. The study area includes dense residential land uses concentrated in the southern portion, with commercial uses and high frequency transit in the northern portion. A major freeway with limited crossings separates the north and south. The existing freeway crossings are roughly one mile apart and rated poorly for bicycle and pedestrian access. This case study considers a new crossing between the existing crossings: first as an exclusive bicycle and pedestrian crossing with heavy traffic calming along the connecting streets (Alternative 1), and then as a multimodal connection for bicycles, pedestrians, and drivers (Alternative 2). It also considers a mixed-use development in the southern portion of the study area. This type of analysis could include other types of improvements not shown here, such as changes to the speed or frequency of the adjacent train line.

The results are reported across all households within a one-mile radius around the new crossing and across low-income households within the same area. To illustrate metrics for various trip purposes and modes, pedestrian access is reported in terms of a non-work accessibility index, which assigns different weights to different destinations, while bicycle, transit, and driving access are reported in terms of jobs.

BASELINE ACCESSIBILITY

Figure 18 to Figure 21 show baseline accessibility across all four modes before any road improvements or land use changes are made. Most notably:

- Walking access (non-work destinations) is highest to the east, near a major activity center, and lowest south of the existing freeway.
- Bicycle access (jobs) is fairly uniform throughout the study area.
- Transit access (jobs) is highest along the existing train line, with a noticeable gap south of the freeway, which is an impediment to walking to the train..
- Driving access (jobs) is exceptionally high compared to other modes.

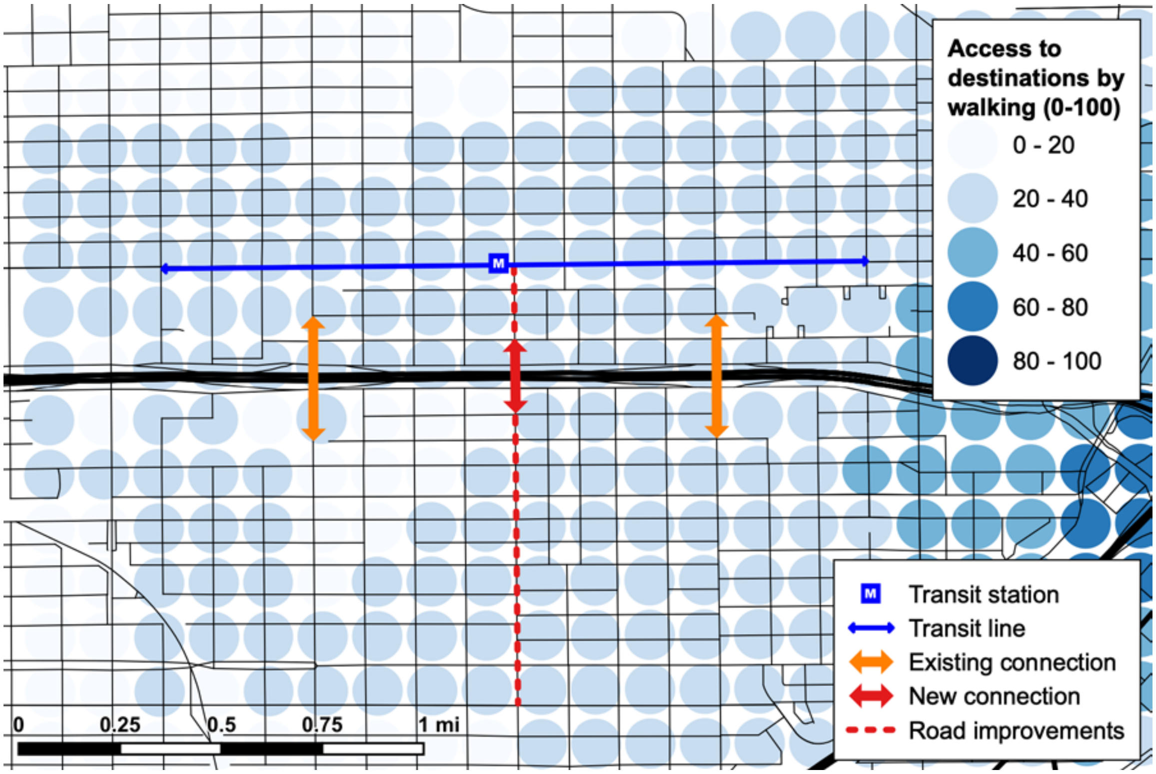

Figure 18. Baseline walking access to non-work destinations (0-100 scale).

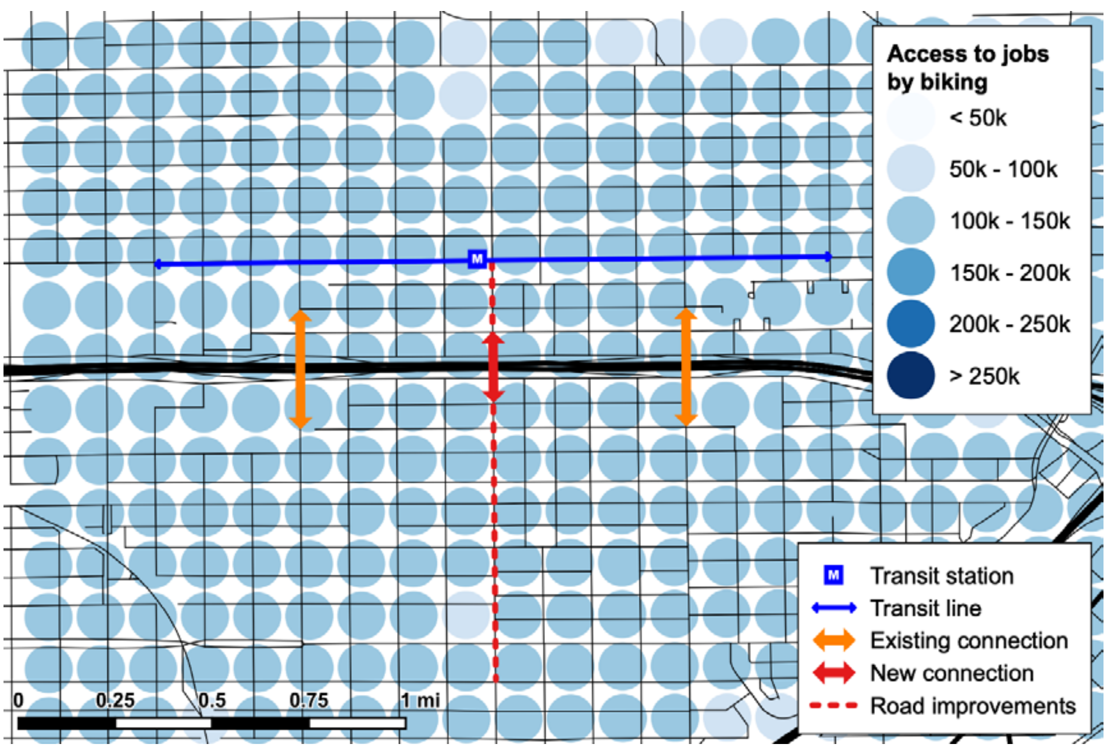

Figure 19. Baseline biking access to jobs.

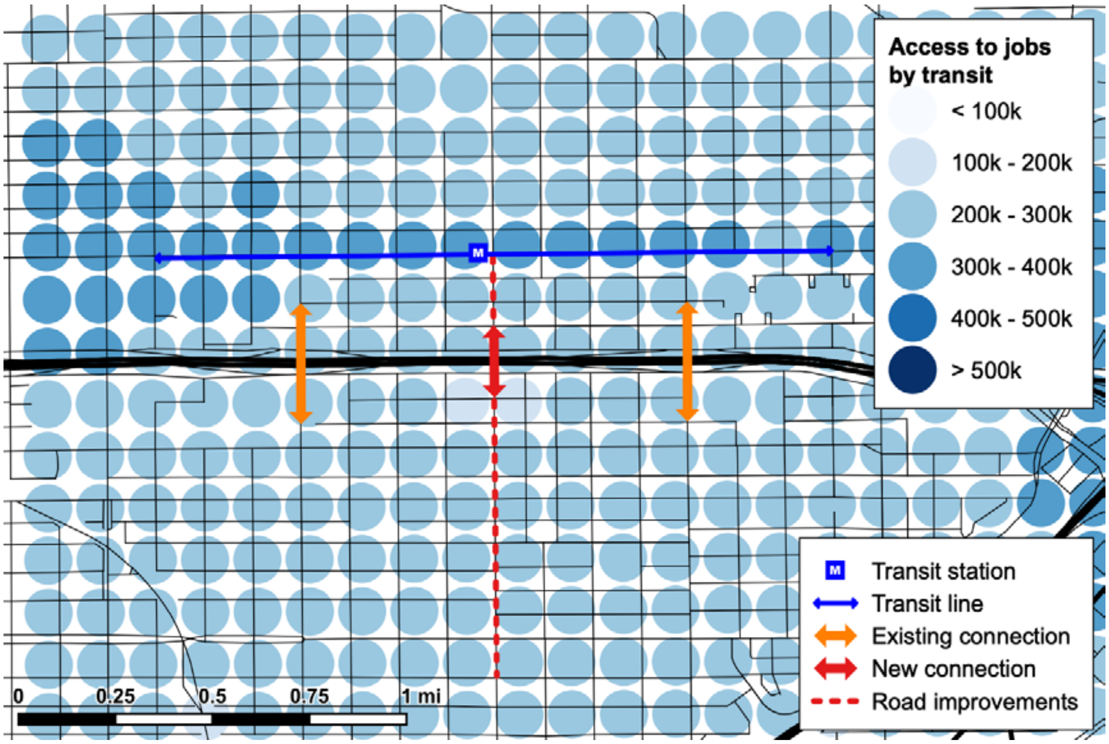

Figure 20. Baseline transit access to jobs.

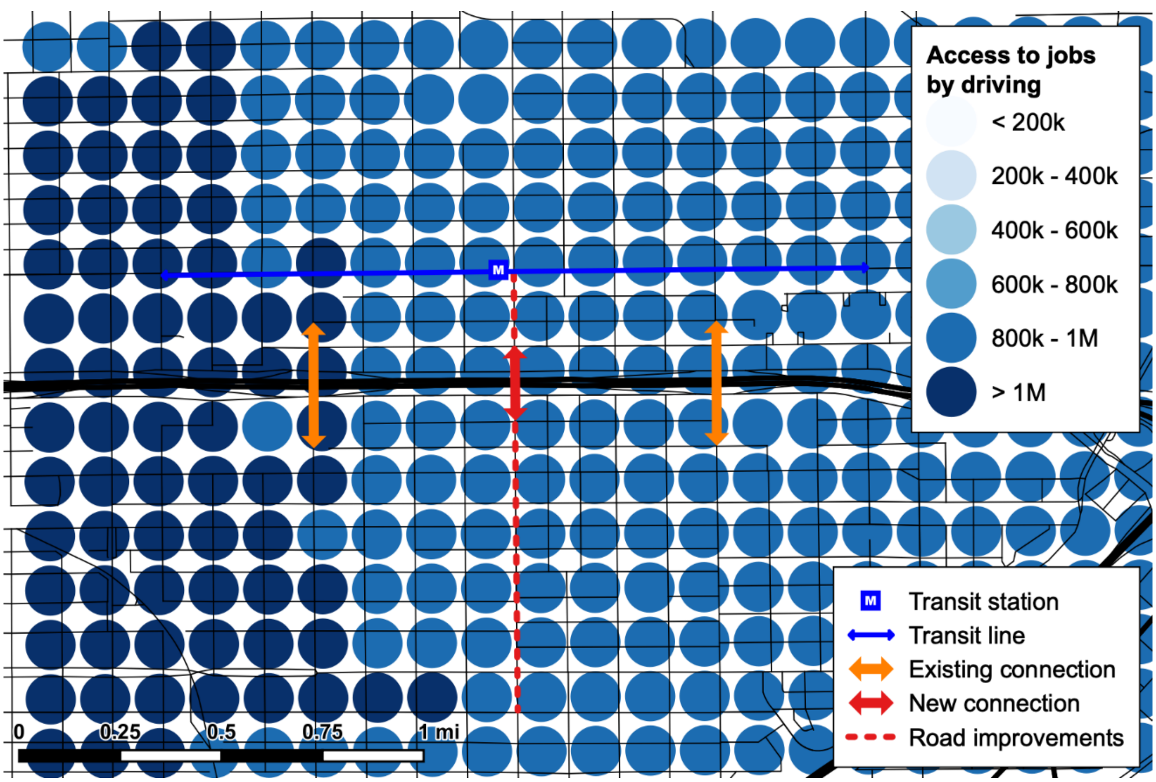

Figure 21. Baseline driving access to jobs.

ALTERNATIVE 1. BICYCLE AND PEDESTRIAN CROSSING WITH TRAFFIC CALMING

Figure 22 to Figure 25 show the impacts of Alternative 1 on access by each mode. The weighted metric is the most useful in evaluating impacts, but cumulative opportunity metrics are also shown for comparison. This alternative adds a bicycle and pedestrian crossing with significant traffic calming along adjoining street segments to the north and south. This project provides considerable benefits for walking, biking, and using transit (by virtue of walking access to the nearest train station). For someone living at point A, the walking time to the train station drops from 30 to 16 minutes, and the biking time drops from 13 to 6 minutes. The traffic calming has a small adverse impact on driving, shown in Figure 25.

The project's average household impact, reported as cumulative accessibility metrics at 10-minute intervals and a travel time decay-weighted metric, are summarized in Table 7. These values are calculated first by estimating the accessibility of each zone (roughly 250-meter cells, in this case), then weighting each zone by its number of households before estimating the average accessibility for the project area (a one-mile radius). Similar results for low-income households are shown in Table 8.

Table 7. Average household accessibility based on Alternative 1.

Travel time	Walking (non-work)		Biking (jobs in 000s)		Transit (jobs in 000s)		Driving (jobs in 000s)	
	Baseline	Alt. 1	Baseline	Alt. 1	Baseline	Alt. 1	Baseline	Alt. 1
10	3.4	3.5	14.4	15.3	1.9	1.9	297.3	296.9
20	18.8	19.3	82.1	83.8	11.7	12.0	1,050.6	1,049.8
30	50.8	52.9	160.1	161.4	67.8	69.8	1,572.3	1,572.0
40	98.9	101.8	226.4	227.7	149.4	150.8	1,730.7	1,730.6
50	150.9	153.0	337.2	339.1	287.9	292.2	1,756.9	1,756.9
60	196.0	197.9	533.7	537.2	468.1	471.8	1,757.6	1,757.6
Weighted	**25.0**	**25.5**	**107.5**	**108.8**	**257.8**	**260.3**	**982.5**	**982.2**
Change	**2.3%**		**1.2%**		**1.0%**		**0.0%**	

Table 8. Average low-income household accessibility based on Alternative 1.

Travel time	Walking (non-work)		Biking (jobs in 000s)		Transit (jobs in 000s)		Driving (jobs in 000s)	
	Baseline	Alt. 1	Baseline	Alt. 1	Baseline	Alt. 1	Baseline	Alt. 1
10	3.5	3.5	14.7	15.5	1.7	1.8	296.6	296.2
20	19.4	19.9	83.2	85.0	12.2	12.5	1,046.2	1,045.5
30	53.2	55.2	161.3	162.7	69.6	71.9	1,571.6	1,571.4
40	101.0	103.8	226.4	227.6	152.4	154.1	1,730.5	1,730.5
50	152.4	154.7	336.4	338.3	297.4	302.2	1,756.9	1,756.9
60	197.7	199.6	527.7	531.2	471.2	475.3	1,757.6	1,757.6
Weighted	**25.5**	**26.1**	**107.7**	**109.0**	**260.7**	**263.5**	**981.3**	**980.9**
Change	**2.2%**		**1.2%**		**1.1%**		**0.0%**	

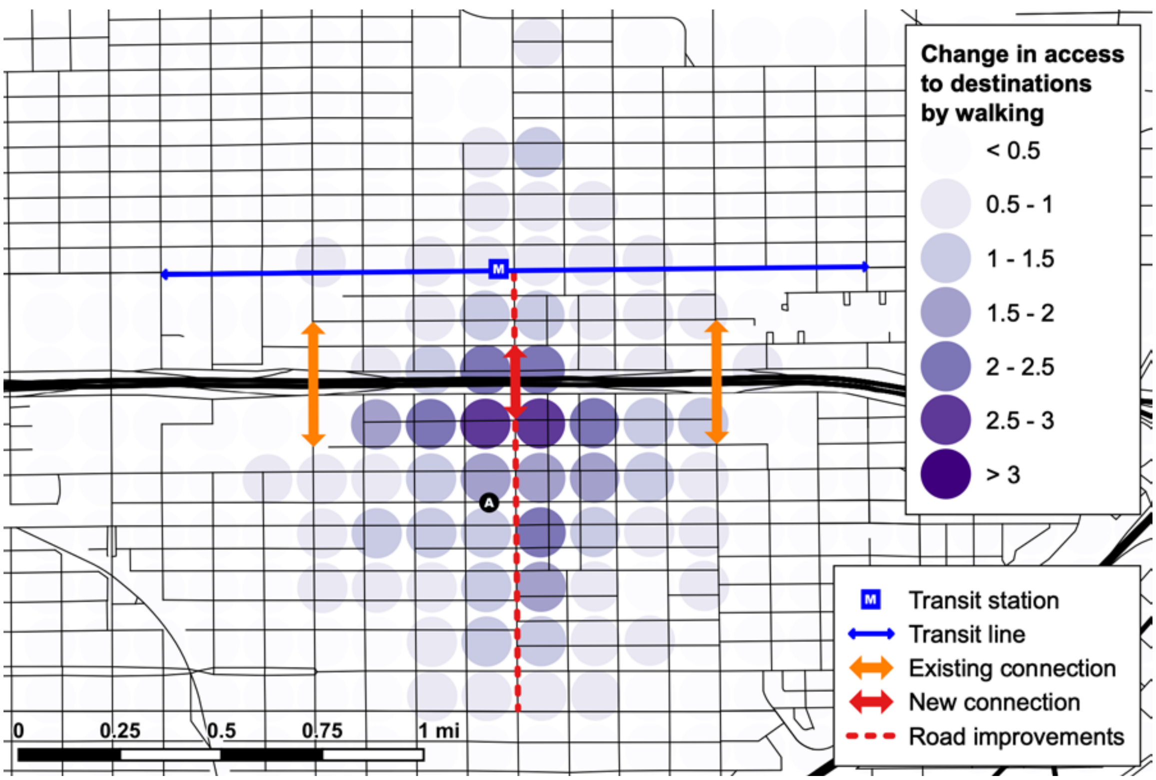

Figure 22. Impacts of bike and pedestrian improvements (Alt. 1) on walking access to non-work destinations (0-100 scale).

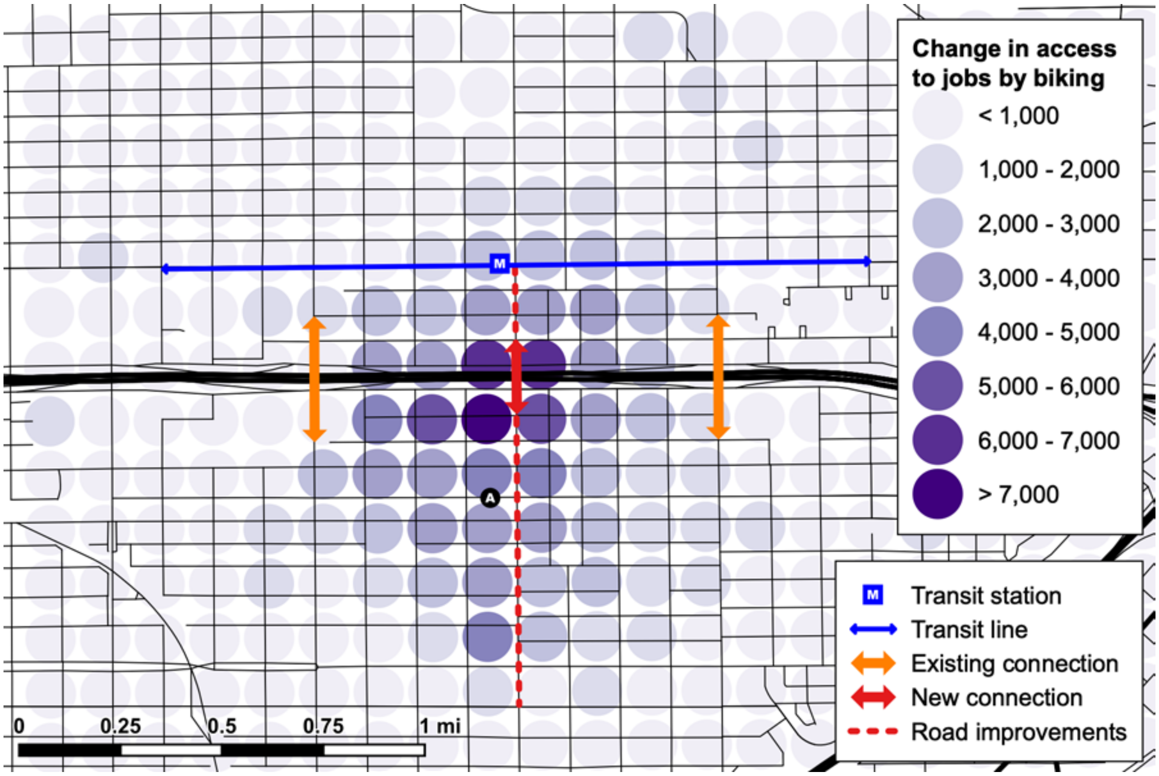

Figure 23. Impacts of bike and pedestrian improvements (Alt. 1) on biking access to jobs.

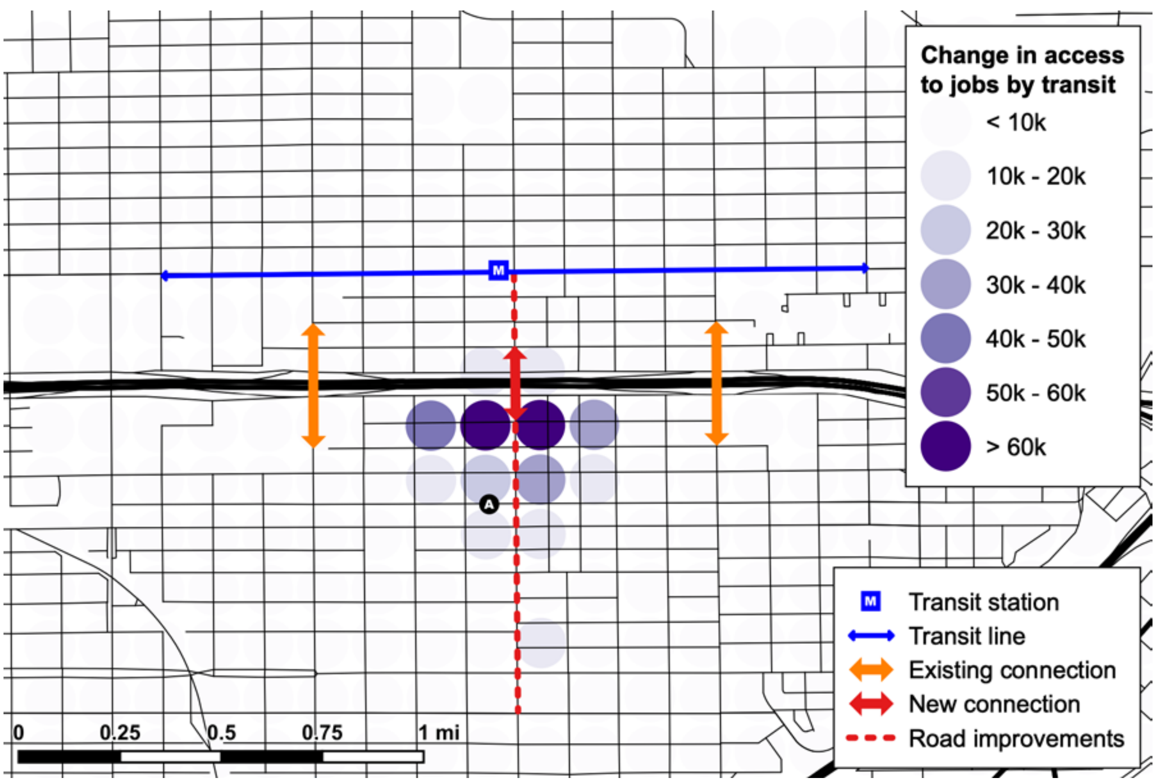

Figure 24. Impacts of bike and pedestrian improvements (Alt. 1) on transit access to jobs.

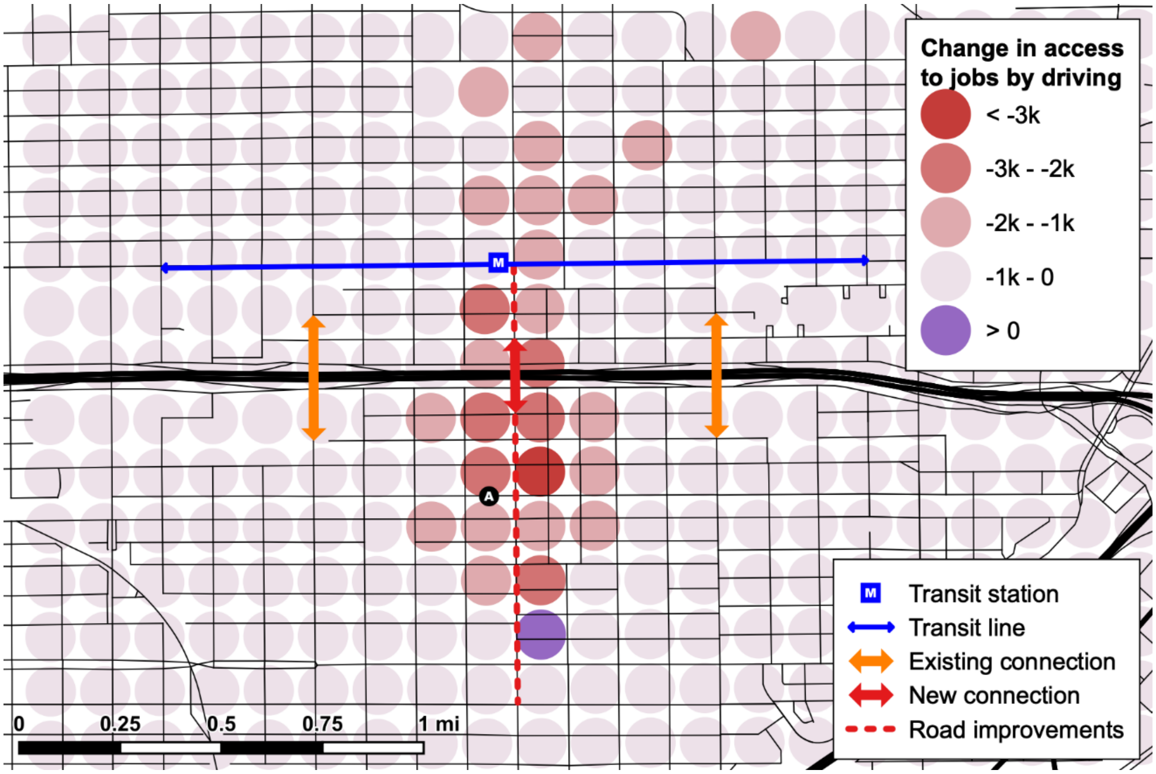

Figure 25. Impacts of bike and pedestrian improvements (Alt. 1) on driving access to jobs.

ALTERNATIVE 2. BICYCLE, PEDESTRIAN AND DRIVING CROSSING

Figure 26 to Figure 29 show the impacts of Alternative 2 on access by each mode. This alternative adds a street crossing for bicycles and pedestrians as before, but also for driving, and therefore it does not offer the same level of comfort for bicycles and pedestrians. So this project provides benefits for all four modes. Compared to Alternative 1, however, non-auto accessibility suffers while driving accessibility is slightly improved. For someone living at point A, the walking time to the train station increases by 2 minutes and the biking time increases by one minute, compared to Alternative 1. The average household impacts are summarized in Table 9 and Table 10.

Table 9. Average household accessibility based on Alternative 2.

Travel time	Walking (non-work)		Biking (jobs in 000s)		Transit (jobs in 000s)		Driving (jobs in 000s)	
	Baseline	Alt. 2	Baseline	Alt. 2	Baseline	Alt. 2	Baseline	Alt. 2
10	3.4	3.4	14.4	15.0	1.9	1.9	297.3	298.3
20	18.8	19.2	82.1	83.0	11.7	11.9	1,050.6	1,051.9
30	50.8	52.3	160.1	160.8	67.8	69.0	1,572.3	1,572.9
40	98.9	100.7	226.4	227.2	149.4	150.1	1,730.7	1,730.8
50	150.9	152.1	337.2	338.3	287.9	290.6	1,756.9	1,756.9
60	196.0	197.2	533.7	535.3	468.1	470.5	1,757.6	1,757.6
Weighted	**25.0**	**25.3**	**107.5**	**108.3**	**257.8**	**259.4**	**982.5**	**983.3**
Change	**1.5%**		**0.7%**		**0.6%**		**0.1%**	

Table 10. Average low-income household accessibility based on Alternative 2.

Travel time	Walking (non-work)		Biking (jobs in 000s)		Transit (jobs in 000s)		Driving (jobs in 000s)	
	Baseline	Alt. 2	Baseline	Alt. 2	Baseline	Alt. 2	Baseline	Alt. 2
10	3.5	3.5	14.7	15.3	1.7	1.7	296.6	297.8
20	19.4	19.8	83.2	84.3	12.2	12.4	1,046.2	1,047.8
30	53.2	54.6	161.3	162.2	69.6	71.0	1,571.6	1,572.4
40	101.0	102.7	226.4	227.2	152.4	153.3	1,730.5	1,730.7
50	152.4	153.7	336.4	337.5	297.4	300.6	1,756.9	1,756.9
60	197.7	198.9	527.7	529.3	471.2	474.1	1,757.6	1,757.6
Weighted	**25.5**	**25.9**	**107.7**	**108.4**	**260.7**	**262.6**	**981.3**	**982.2**
Change	**1.5%**		**0.7%**		**0.7%**		**0.1%**	

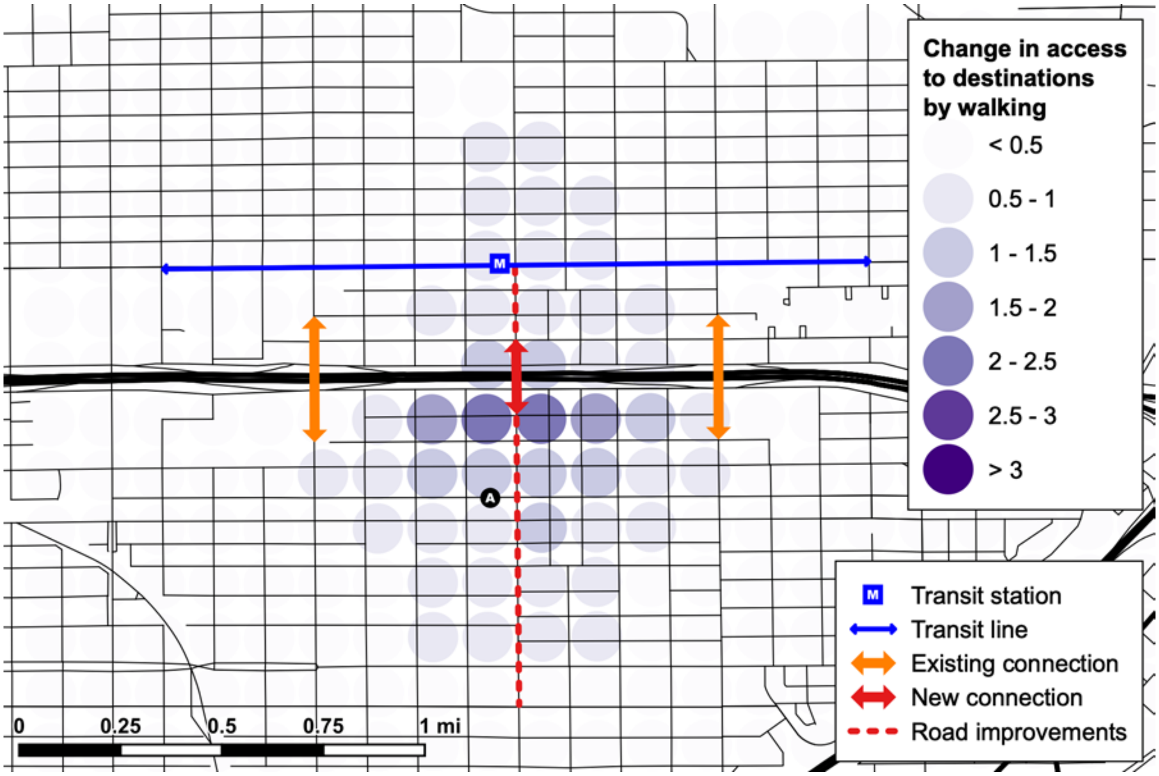

Figure 26. Impacts of bike, pedestrian and driving improvements (Alt. 2) on walking access to non-work destinations (0-100 scale).

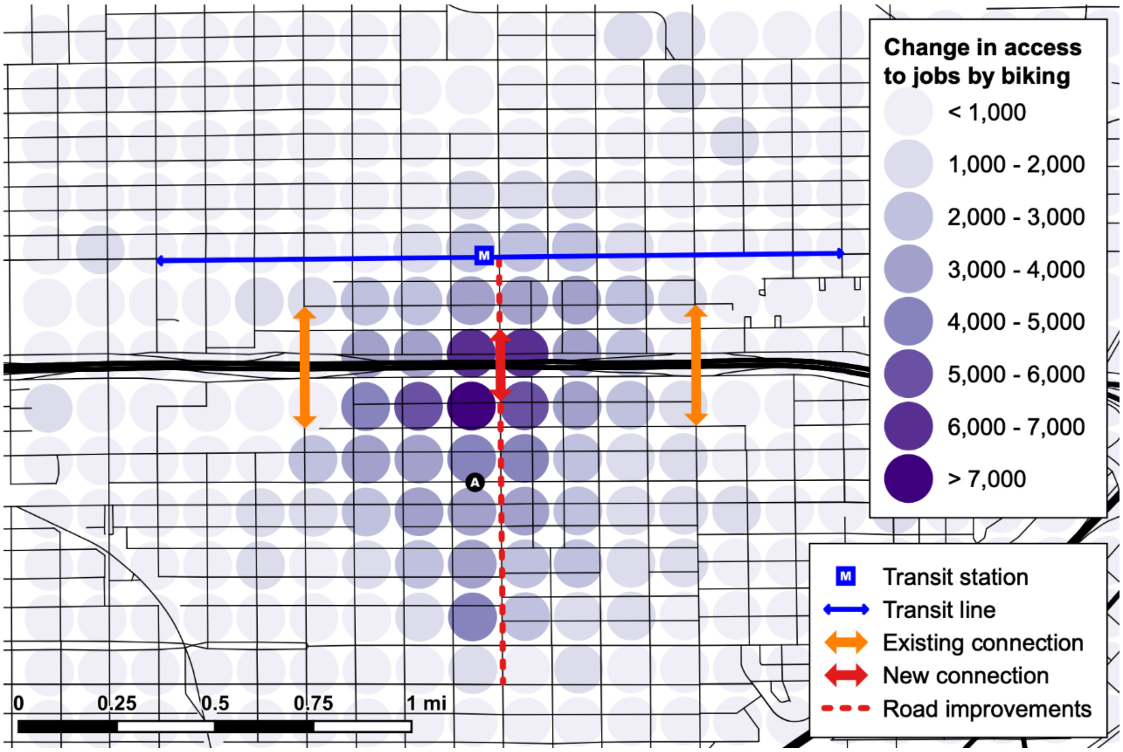

Figure 27. Impacts of bike, pedestrian and driving improvements (Alt. 2) on biking access to jobs.

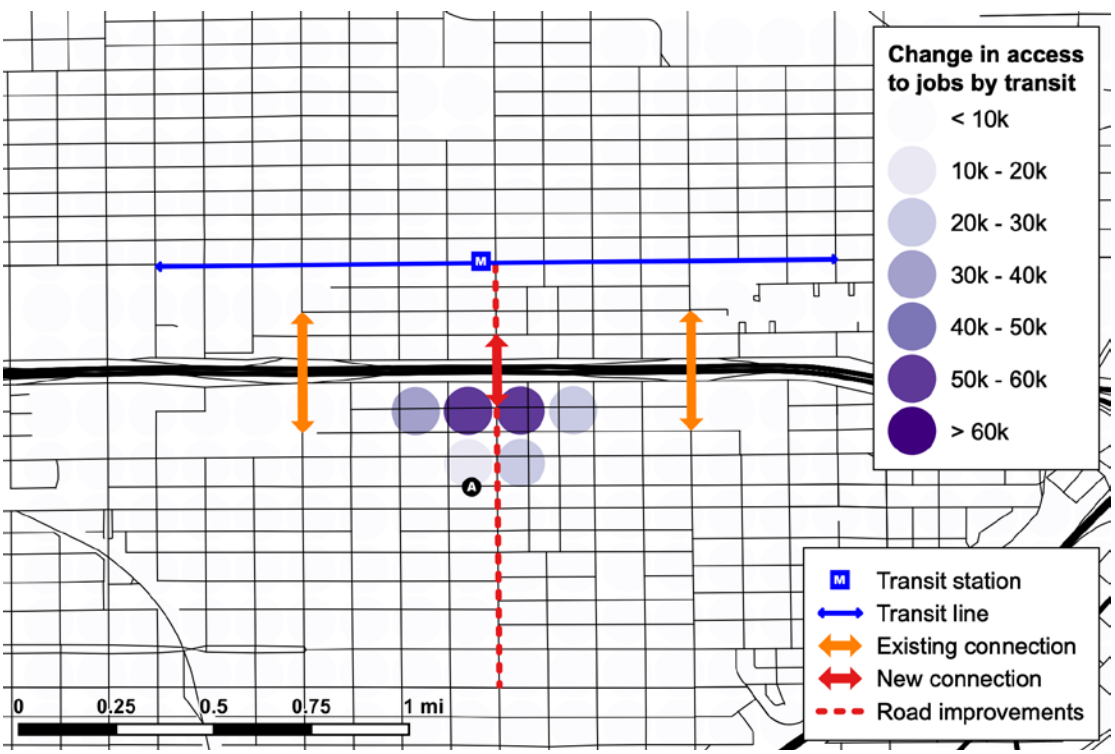

Figure 28. Impacts of bike, pedestrian and driving improvements (Alt. 2) on transit access to jobs.

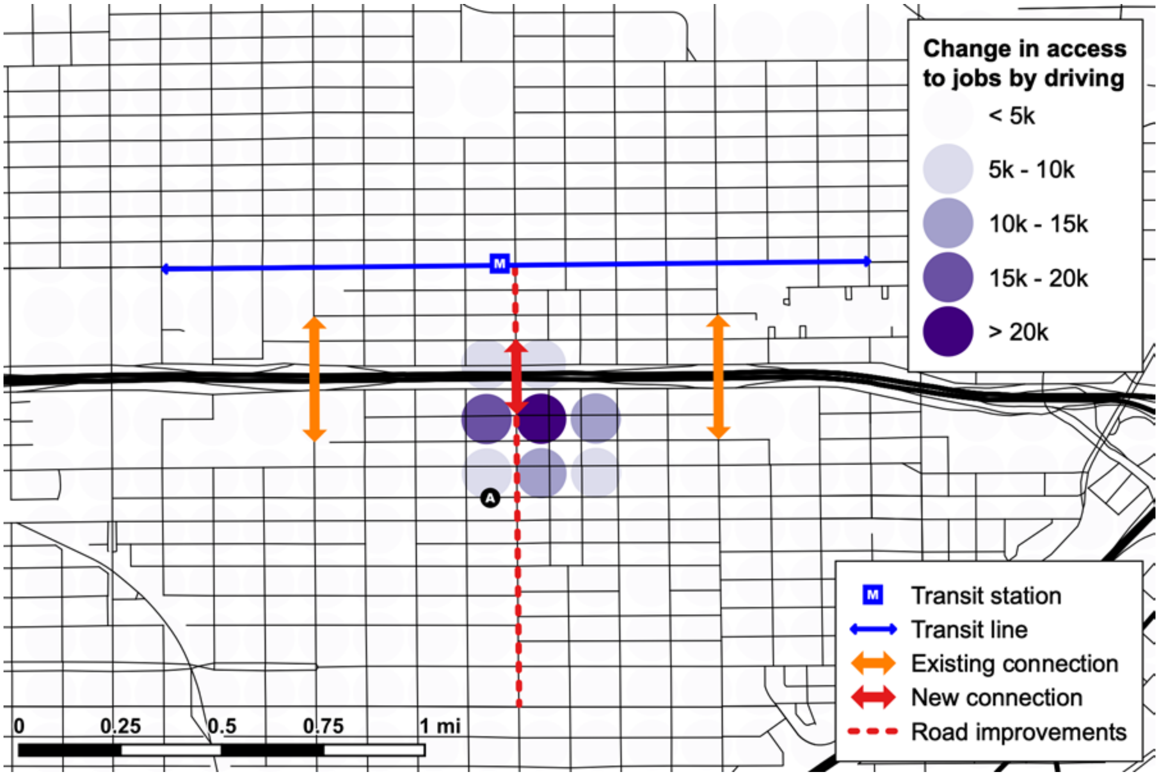

Figure 29. Impacts of bike, pedestrian and driving improvements (Alt. 2) on driving access to jobs.

INFILL DEVELOPMENT

Figure 30 to Figure 33 show the impacts of infill development at the southern end of the connecting route, with no transportation improvements. The proposed development adds 2,000 jobs and a cluster of POIs, such as stores and services, worth 3 out of 100 points in a hypothetical non-work score. The average household impacts are summarized in Table 11. Low-income households were not evaluated separately in this scenario.

Table 11. Average household accessibility based on infill development.

Travel time	Walking (non-work)		Biking (jobs in 000s)		Transit (jobs in 000s)		Driving (jobs in 000s)	
	Baseline	Infill	Baseline	Infill	Baseline	Infill	Baseline	Infill
10	3.4	4.4	14.4	15.4	1.9	2.1	297.3	299.0
20	18.8	21.3	82.1	83.8	11.7	12.5	1,050.6	1,052.3
30	50.8	54.2	160.1	161.8	67.8	69.0	1,572.3	1,574.0
40	98.9	103.9	226.4	228.1	149.4	151.1	1,730.7	1,732.4
50	150.9	156.7	337.2	338.9	287.9	289.6	1,756.9	1,758.7
60	196.0	201.9	533.7	535.4	468.1	469.9	1,757.6	1,759.3
Weighted	**25.0**	**26.7**	**107.5**	**108.8**	**257.8**	**259.2**	**982.5**	**984.2**
Change	**7.0%**		**1.2%**		**0.6%**		**0.2%**	

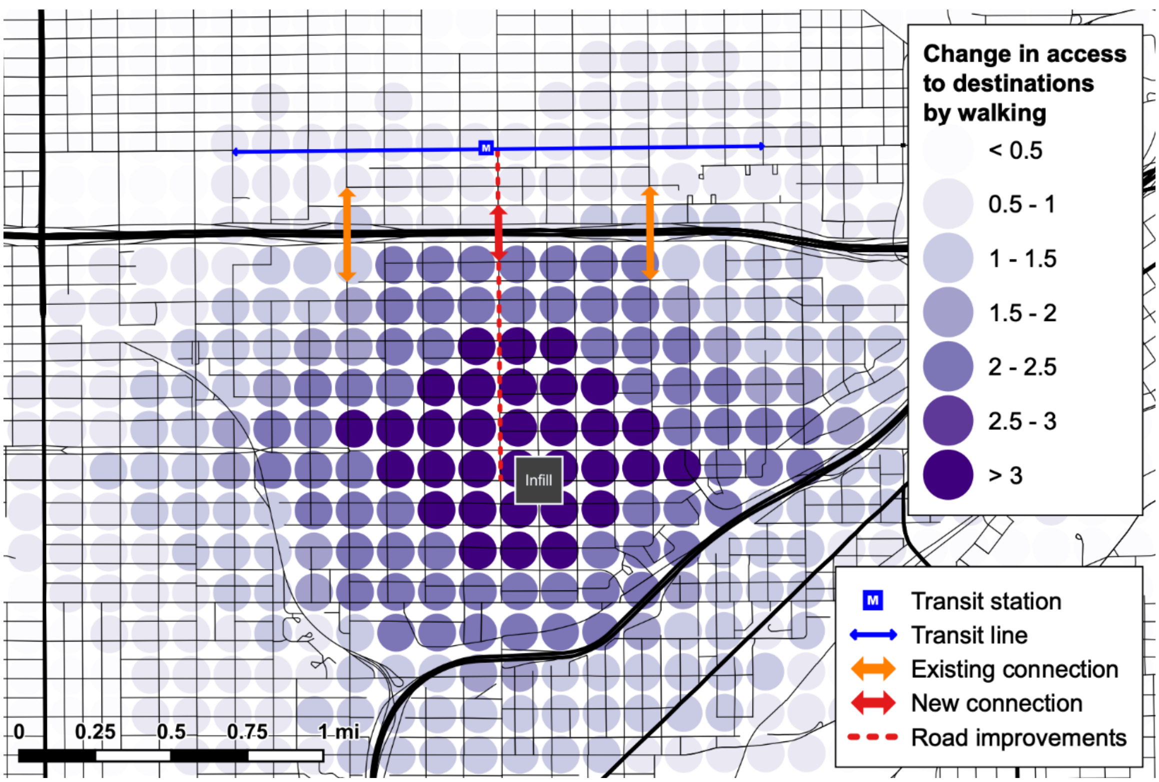

Figure 30. Impacts of infill development on walking access to non-work destinations (0-100 scale).

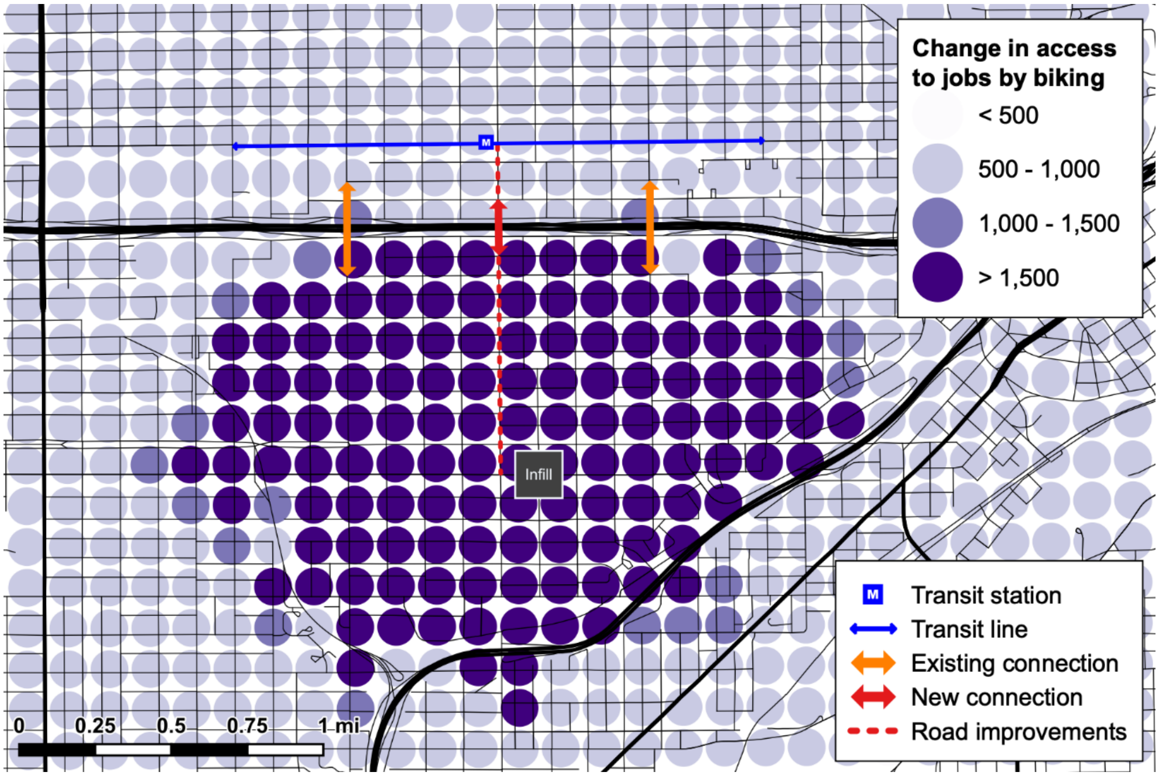

Figure 31. Impacts of infill development on biking access to jobs.

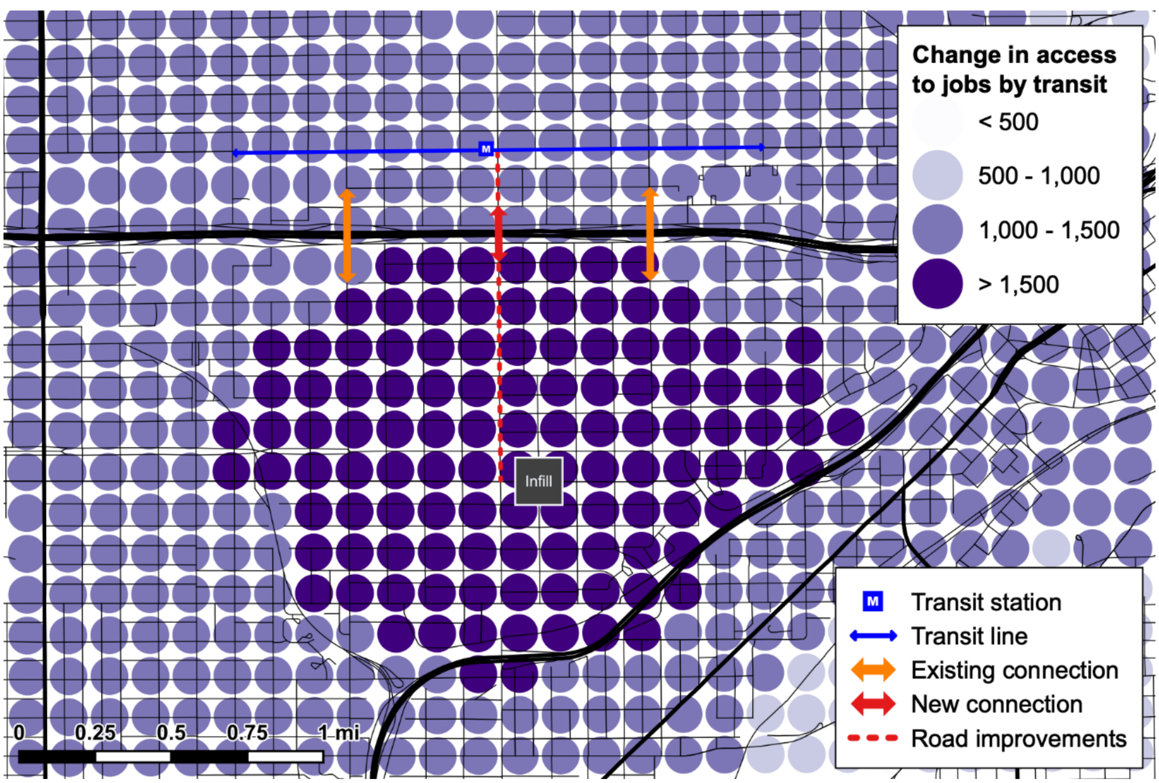

Figure 32. Impacts of infill development on transit access to jobs.

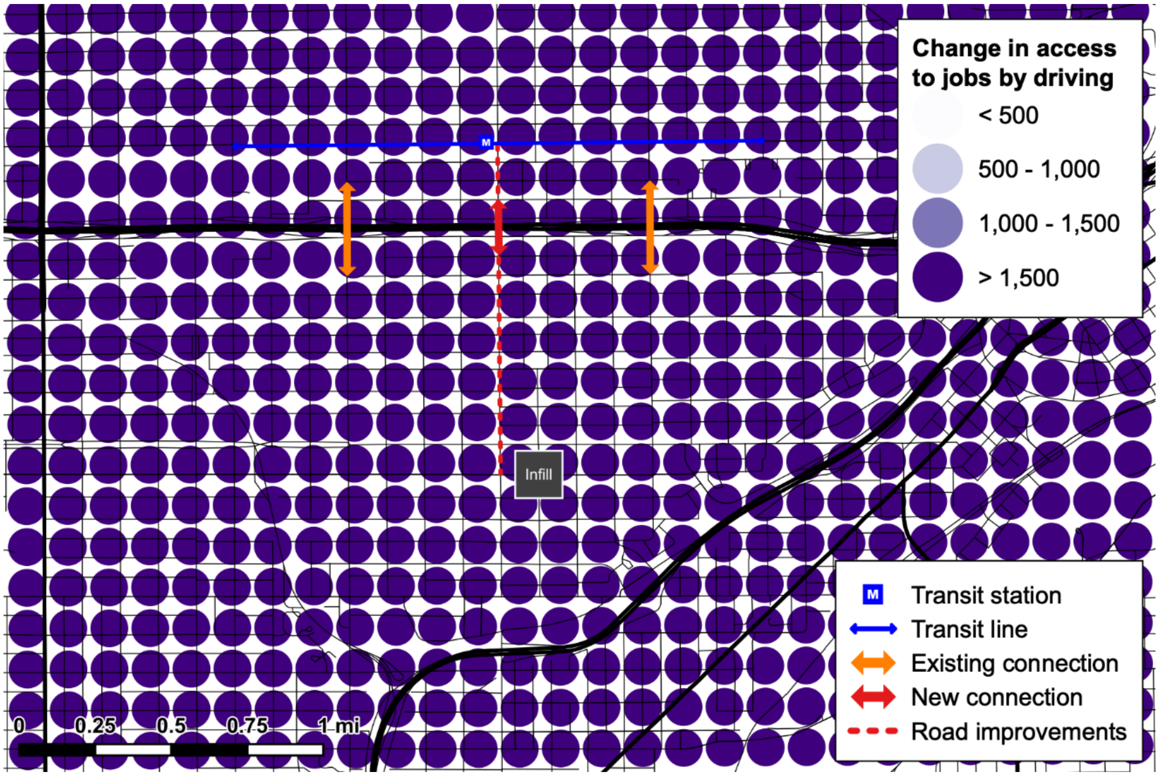

Figure 33. Impacts of infill development on driving access to jobs.

EVALUATING PROJECTS

The three alternatives presented above can be evaluated various ways depending on broad policy goals. The changes in accessibility for each mode are described in Table 12 using six metrics: the average household impact, the total household impact, the percent change across all households, and the same three metrics for low-income households. These metrics on their own give useful insight about project impacts, but project evaluation requires some decisions and value judgments by policy makers. For instance, the benefits to each mode can be assigned equal weight and combined into a multimodal accessibility score, or each mode can be assigned different weights based on equity-related goals, mode shift goals, or models describing the relationship of each mode to VMT.

Table 12. Evaluation metrics for projects.

	Alternative 1	Alternative 2	Infill
Average impact (households)			
Walking (non-work)	0.566	0.381	1.739
Biking (jobs)	1,287	754	1,309
Transit (jobs)	2,474	1,580	1,421
Driving (jobs)	-328	754	1,653
Total impact (households)			
Walking (non-work)	6,642	4,469	20,401
Biking (jobs)	15,095,895	8,843,920	15,349,474
Transit (jobs)	29,019,524	18,537,084	16,666,507
Driving (jobs)	-3,846,485	8,838,816	19,393,061
Percent change (households)			
Walking (non-work)	2.27%	1.53%	6.97%
Biking (jobs)	1.20%	0.70%	1.22%
Transit (jobs)	0.96%	0.61%	0.55%
Driving (jobs)	-0.03%	0.08%	0.17%
Average impact (low-income households)			
Walking (non-work)	0.5669	0.3807	*N/A*
Biking (jobs)	1,302	776	*N/A*
Transit (jobs)	2,799	1,898	*N/A*
Driving (jobs)	-335	878	*N/A*
Total impact (low-income households)			
Walking (non-work)	2,876	1,932	*N/A*
Biking (jobs)	6,608,779	3,937,905	*N/A*
Transit (jobs)	14,200,963	9,629,359	*N/A*
Driving (jobs)	-1,699,241	4,453,048	*N/A*
Percent change (low-income households)			
Walking (non-work)	2.22%	1.49%	*N/A*
Biking (jobs)	1.21%	0.72%	*N/A*
Transit (jobs)	2.60%	1.76%	*N/A*
Driving (jobs)	-0.31%	0.82%	*N/A*

MODELING RELATED TRAVEL OUTCOMES

There is plenty of work showing the links between accessibility and travel behavior, so accessibility metrics present a valuable opportunity to score projects based on their potential to advance goals related to transit use, mode shift, and VMT reduction. This can be done using a simple weighting scheme or through more involved modeling efforts.

Modeling can present challenges, mainly because automobile use (VMT and mode share) tends to decrease as automobile accessibility increases. This is because auto accessibility is influenced largely by proximity to major activity centers, where walking, biking and transit are often comparable to driving, if not more efficient. Logically, improving auto accessibility in these places—especially by adding road capacity—would likely increase driving. These nuances can be teased out through careful modeling or by adhering to the following general framework:

$$\text{Automobile use} \propto \text{Auto accessibility} / \text{Non-auto accessibility}$$

In other words, automobile use is roughly proportional to the ratio of auto to non-auto accessibility. Of course, the relative impacts of walk, bike and transit access can vary from place to place.

Good modeling also often calls for a fair number of control variables—notably things like income and vehicle ownership. While these more complex models might produce more accurate and reliable estimates of travel behavior, it is important to consider how important they are in project evaluation. For instance, these demographic considerations are likely to change not long after transportation investments are made and often even because of those investments. It might be more useful, therefore, to simply consider the directionality and rough magnitude of project impacts than trying to estimate more precise outcomes. Analysts constructing regression models should also be aware that modal accessibilities tend to correlate with each other. The ratio approach avoids this problem.

Finally, it is worth noting that estimates of VMT and related outcomes such as emissions will capture short-term effects. If a transportation facility or land use change induces more land use changes, as highway expansions tend to do, our accessibility analysis will not automatically account for them.

CONCLUDING REMARKS

Accessibility metrics have the potential to address policy goals in ways that conventional measures of speed and delay, or model-derived values, cannot. Yet a big caveat is in order: Accessibility metrics are not a substitute for thinking.

For one thing, there's more to decisions than accessibility. In transportation, for example, policy goals include items like state of good repair, which is not really measured through accessibility, and safety, which is only partially accounted for through level of traffic stress.

Moreover, even in questions related to new transportation capacity, where accessibility can apply, the concept needs to be used thoughtfully.

Consider a new or expanded downtown freeway. Even accounting for the land uses that would be displaced, such a facility likely would show an increase in accessibility to jobs by auto. If we simply wanted to raise accessibility, the freeway might be a good option. (Which is the reasoning behind downtown freeways in the first place.)

As with those bullet-riddled World War II planes, not only do we need to measure the right thing, but we also have to think about what the measure is telling us. Accessibility is in many ways a better measure than others, but we need to use it well. How might we think of a new downtown expressway beyond just adding up the new auto accessibility it would provide?

One way would be to consider the effects on accessibility by all modes. A new freeway would likely impede travel by other modes, reducing accessibility. So as a start we could consider the net change in accessibility across all modes (auto increase minus other decreases).

But that may not change the analysis by much. In most parts of U.S. metro areas, auto accessibility is often orders of magnitude greater than that of other modes, so changes in the auto network can have much larger net accessibility impacts. We might then want to normalize the changes by looking at the percentage change in accessibility for each mode rather than the absolute changes. Viewed this way, a downtown freeway might seem like a less-appealing option.

We might also consider costs. A downtown freeway would be an expensive megaproject. We might normalize the accessibility impacts of projects by dividing their costs—preferably not just capital costs, but full lifecycle costs and negative externalities, to the extent possible. With this lens, the freeway starts to look even less appealing.

But there’s more. If our policy goals involve reducing emissions and/or congestion, we can use modal accessibility metrics to estimate the relative change in VMT from the new freeway. If it reduces walk, bike, and transit accessibility, while boosting auto accessibility, it will drive VMT up, creating more traffic and emissions. (And we need to remember that is only a short-term estimate, and that with longer-term induced land-use changes, the VMT effect will be greater.) Now the freeway may look more like an expensive mistake—just like putting armor on the wings of those planes would have been.

As practitioners, however, we do not usually have the luxury of creating a bespoke analysis like the one just described for every decision that comes along. One of the reasons LOS has been so enduring is that it provides well-understood rules of thumb, which accessibility now lacks. But the good news is that once we have the basics of measurement and have considered what the metrics tell us, we can come up with those rules. We could:

- Calculate accessibility gains from transportation projects and divide by cost to compare across projects. Active transportation projects will typically show less benefit than highways and transit projects, but they will also generally cost much less, so the relative return on investment will be notable. Land use projects may turn out to be even better investments. Consider the costs of providing health care or education in an underserved area compared to the cost of transporting patients or students to distant facilities, for example.
- Set a multimodal standard that requires a transportation program to better balance modal accessibilities. For example, we could calculate accessibility changes by mode and require that the program not exacerbate auto-centricity—i.e., the ratio of non-auto accessibility gains to auto accessibility gains should be positive.
- Set minimum accessibility standards, perhaps by walking, for new land use area plans or subdivisions, to common destinations such as retail and parks.
- Establish comprehensive plans and corresponding zoning that concentrates new employment in areas that meet a minimum standard of access to workers by transit.
- Use accessibility metrics to estimate VMT impacts, remembering that long-term VMT changes will be greater than these estimates, and either reject projects that increase VMT or require mitigation.
- Replace LOS-based traffic impact assessments for land-use developments with VMT estimates based on accessibility metrics and require mitigation that reduces VMT, such as transportation demand management measures.
- Estimate modal usage based on accessibility to assess and prioritize transportation projects that do not get picked up by travel demand models, like facilities for walking and biking.

The list could go on, and it will as more and more practitioners make creative use of accessibility metrics. A few advances we can foresee include algorithms to identify the most impactful improvements to transportation facilities and ways to account for the diminishing marginal returns of additional accessible destinations. There will be other advances we cannot yet foresee.

This guide has described the data and tools we can use to measure accessibility, as well as a cumulative opportunities metric that we can use to report accessibility. Armed with this guide, a practitioner should be able to analyze transportation and land use in terms of accessibility. And as that work proceeds, and tools and data improve, there will be exciting new developments in the field that will require new guidance, or an update to this document.

It's a great time to be working in transportation and land use decision-making.

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APPENDIX: DECAY FUNCTIONS

The following tables show exponential travel time decay functions for work and non-work trips by mode and the observed values from the 2017 National Household Travel Survey in one-minute increments.

Table 13. Exponential decay functions derived from the 2017 NHTS

Mode	Home-based work	Home-based non-work
All modes	$1.162\ e^{-0.0416\ t}$ (n = 115,438)	$1.122\ e^{-0.0632\ t}$ (n = 480,330)
Walking	$1.049\ e^{-0.0684\ t}$ (n = 3,136)	$1.000\ e^{-0.0631\ t}$ (n = 53,629)
Biking	$1.256\ e^{-0.0565\ t}$ (n = 1,215)	$1.060\ e^{-0.0575\ t}$ (n = 5,134)
Transit	$1.266\ e^{-0.0195\ t}$ (n = 3,686)	$1.215\ e^{-0.0229\ t}$ (n = 5,211)
Driving	$1.185\ e^{-0.0448\ t}$ (n = 107,401)	$1.157\ e^{-0.0668\ t}$ (n = 416,356)

Table 14. Observed utility values based on travel time distributions in the 2017 NHTS

Time (min)	Home-based work					Home-based non-work				
	All	Walk	Bike	Transit	Drive	All	Walk	Bike	Transit	Drive
1	0.99	0.95	1.00	1.00	1.00	0.98	0.92	0.97	1.00	0.99
2	0.99	0.90	1.00	1.00	0.99	0.96	0.88	0.93	1.00	0.98
3	0.98	0.87	1.00	1.00	0.98	0.94	0.85	0.92	1.00	0.96
4	0.97	0.86	0.99	1.00	0.98	0.93	0.83	0.90	1.00	0.94
5	0.91	0.68	0.95	1.00	0.91	0.80	0.67	0.76	0.99	0.81
6	0.90	0.67	0.94	1.00	0.91	0.78	0.65	0.75	0.99	0.80
7	0.89	0.65	0.93	0.99	0.89	0.76	0.63	0.74	0.99	0.77
8	0.88	0.64	0.91	0.99	0.88	0.74	0.62	0.72	0.99	0.75
9	0.87	0.63	0.90	0.99	0.88	0.72	0.61	0.71	0.99	0.73
10	0.78	0.51	0.77	0.99	0.78	0.56	0.48	0.55	0.96	0.57
11	0.77	0.50	0.75	0.99	0.77	0.55	0.47	0.54	0.96	0.56
12	0.76	0.48	0.71	0.99	0.76	0.54	0.46	0.53	0.96	0.54
13	0.75	0.47	0.70	0.99	0.74	0.53	0.46	0.53	0.96	0.52
14	0.74	0.46	0.69	0.99	0.74	0.51	0.45	0.52	0.95	0.51
15	0.61	0.32	0.50	0.96	0.60	0.36	0.33	0.38	0.89	0.36
16	0.60	0.32	0.49	0.96	0.59	0.36	0.32	0.37	0.89	0.35
17	0.59	0.31	0.48	0.96	0.58	0.35	0.32	0.36	0.88	0.34
18	0.58	0.31	0.47	0.96	0.57	0.34	0.31	0.36	0.88	0.33
19	0.58	0.31	0.47	0.96	0.56	0.34	0.31	0.35	0.87	0.32

Table 14. Continued

Time (min)	Home-based work					Home-based non-work				
	All	Walk	Bike	Transit	Drive	All	Walk	Bike	Transit	Drive
20	0.50	0.23	0.37	0.93	0.48	0.26	0.25	0.28	0.83	0.25
21	0.49	0.22	0.37	0.93	0.47	0.26	0.24	0.28	0.82	0.25
22	0.48	0.22	0.35	0.93	0.46	0.25	0.24	0.27	0.82	0.24
23	0.48	0.22	0.35	0.92	0.46	0.25	0.24	0.27	0.82	0.24
24	0.47	0.22	0.35	0.92	0.45	0.25	0.23	0.27	0.81	0.23
25	0.43	0.20	0.30	0.90	0.40	0.22	0.21	0.24	0.77	0.20
26	0.42	0.19	0.30	0.90	0.40	0.21	0.21	0.24	0.77	0.20
27	0.42	0.19	0.30	0.89	0.39	0.21	0.21	0.24	0.76	0.19
28	0.41	0.19	0.29	0.88	0.39	0.21	0.20	0.23	0.76	0.19
29	0.41	0.19	0.29	0.88	0.38	0.20	0.20	0.23	0.75	0.19
30	0.28	0.10	0.17	0.78	0.25	0.13	0.12	0.15	0.60	0.11
31	0.27	0.10	0.16	0.77	0.25	0.12	0.12	0.15	0.60	0.11
32	0.27	0.09	0.16	0.77	0.24	0.12	0.12	0.15	0.60	0.11
33	0.27	0.09	0.16	0.77	0.24	0.12	0.12	0.15	0.59	0.11
34	0.27	0.09	0.16	0.77	0.24	0.12	0.11	0.15	0.59	0.10
35	0.24	0.08	0.13	0.73	0.21	0.10	0.10	0.13	0.57	0.09
36	0.23	0.07	0.13	0.73	0.20	0.10	0.10	0.13	0.56	0.09
37	0.23	0.07	0.13	0.72	0.20	0.10	0.10	0.13	0.56	0.09
38	0.23	0.07	0.12	0.72	0.20	0.10	0.10	0.12	0.56	0.09
39	0.23	0.07	0.12	0.72	0.20	0.10	0.10	0.12	0.56	0.09
40	0.20	0.06	0.10	0.67	0.17	0.09	0.09	0.10	0.51	0.08
41	0.19	0.06	0.10	0.67	0.17	0.09	0.09	0.10	0.51	0.08
42	0.19	0.06	0.09	0.66	0.16	0.09	0.08	0.10	0.50	0.07
43	0.19	0.06	0.09	0.66	0.16	0.09	0.08	0.10	0.50	0.07
44	0.19	0.06	0.09	0.65	0.16	0.08	0.08	0.10	0.50	0.07
45	0.14	0.03	0.05	0.58	0.11	0.07	0.06	0.08	0.41	0.06
46	0.14	0.03	0.05	0.58	0.11	0.06	0.06	0.08	0.41	0.06
47	0.14	0.03	0.05	0.57	0.11	0.06	0.06	0.08	0.41	0.06
48	0.14	0.03	0.05	0.57	0.11	0.06	0.06	0.08	0.41	0.05
49	0.14	0.03	0.05	0.57	0.11	0.06	0.06	0.08	0.41	0.05
50	0.12	0.03	0.03	0.52	0.10	0.06	0.05	0.07	0.37	0.05
51	0.12	0.03	0.03	0.52	0.09	0.06	0.05	0.07	0.37	0.05
52	0.12	0.03	0.03	0.52	0.09	0.06	0.05	0.07	0.37	0.05
53	0.12	0.03	0.03	0.52	0.09	0.06	0.05	0.07	0.37	0.05
54	0.12	0.03	0.03	0.51	0.09	0.06	0.05	0.07	0.37	0.05
55	0.11	0.03	0.03	0.48	0.08	0.05	0.05	0.07	0.35	0.05
56	0.11	0.03	0.03	0.47	0.08	0.05	0.05	0.07	0.35	0.05
57	0.11	0.03	0.03	0.47	0.08	0.05	0.05	0.07	0.35	0.05
58	0.10	0.03	0.03	0.47	0.08	0.05	0.05	0.07	0.34	0.05
59	0.10	0.03	0.03	0.46	0.08	0.05	0.05	0.07	0.34	0.04

Table 14. Continued

Time (min)	Home-based work					Home-based non-work				
	All	Walk	Bike	Transit	Drive	All	Walk	Bike	Transit	Drive
60	0.07	0.02	0.02	0.35	0.05	0.04	0.03	0.04	0.25	0.03
61	0.07	0.02	0.02	0.35	0.05	0.04	0.03	0.04	0.25	0.03
62	0.07	0.02	0.02	0.35	0.05	0.03	0.03	0.04	0.24	0.03
63	0.06	0.02	0.02	0.34	0.05	0.03	0.03	0.04	0.24	0.03
64	0.06	0.02	0.02	0.34	0.05	0.03	0.03	0.04	0.24	0.03
65	0.06	0.01	0.02	0.32	0.04	0.03	0.02	0.04	0.22	0.03
66	0.06	0.01	0.02	0.32	0.04	0.03	0.02	0.04	0.22	0.03
67	0.06	0.01	0.02	0.31	0.04	0.03	0.02	0.04	0.22	0.03
68	0.06	0.01	0.02	0.31	0.04	0.03	0.02	0.04	0.22	0.03
69	0.06	0.01	0.02	0.31	0.04	0.03	0.02	0.04	0.22	0.03
70	0.05	0.01	0.01	0.27	0.04	0.03	0.02	0.04	0.21	0.03
71	0.05	0.01	0.01	0.27	0.04	0.03	0.02	0.04	0.21	0.03
72	0.05	0.01	0.01	0.27	0.03	0.03	0.02	0.04	0.21	0.03
73	0.05	0.01	0.01	0.27	0.03	0.03	0.02	0.04	0.20	0.03
74	0.05	0.01	0.01	0.27	0.03	0.03	0.02	0.03	0.20	0.03
75	0.04	0.01	0.01	0.22	0.03	0.03	0.02	0.02	0.17	0.02
76	0.04	0.01	0.01	0.22	0.03	0.03	0.02	0.02	0.17	0.02
77	0.04	0.01	0.01	0.22	0.03	0.03	0.02	0.02	0.17	0.02
78	0.04	0.01	0.01	0.21	0.03	0.03	0.02	0.02	0.17	0.02
79	0.04	0.01	0.01	0.21	0.03	0.03	0.02	0.02	0.17	0.02
80	0.03	0.01	0.01	0.19	0.02	0.02	0.02	0.02	0.16	0.02
81	0.03	0.01	0.01	0.19	0.02	0.02	0.02	0.02	0.16	0.02
82	0.03	0.01	0.01	0.19	0.02	0.02	0.02	0.02	0.15	0.02
83	0.03	0.01	0.01	0.19	0.02	0.02	0.02	0.02	0.15	0.02
84	0.03	0.01	0.01	0.19	0.02	0.02	0.02	0.02	0.15	0.02
85	0.03	0.01	0.01	0.18	0.02	0.02	0.02	0.02	0.15	0.02
86	0.03	0.01	0.01	0.18	0.02	0.02	0.02	0.02	0.15	0.02
87	0.03	0.01	0.01	0.18	0.02	0.02	0.02	0.02	0.15	0.02
88	0.03	0.01	0.01	0.18	0.02	0.02	0.02	0.02	0.15	0.02
89	0.03	0.01	0.01	0.18	0.02	0.02	0.02	0.02	0.15	0.02
90	0.02	0.00	0.01	0.12	0.01	0.02	0.01	0.02	0.10	0.02
91	0.02	0.00	0.01	0.12	0.01	0.02	0.01	0.02	0.10	0.02
92	0.02	0.00	0.01	0.11	0.01	0.02	0.01	0.02	0.10	0.02
93	0.02	0.00	0.01	0.11	0.01	0.02	0.01	0.02	0.10	0.02
94	0.02	0.00	0.01	0.11	0.01	0.02	0.01	0.02	0.10	0.02
95	0.02	0.00	0.01	0.10	0.01	0.02	0.01	0.02	0.09	0.02
96	0.02	0.00	0.01	0.10	0.01	0.02	0.01	0.02	0.09	0.02
97	0.02	0.00	0.01	0.10	0.01	0.02	0.01	0.02	0.09	0.02
98	0.02	0.00	0.01	0.10	0.01	0.02	0.01	0.02	0.09	0.02
99	0.02	0.00	0.01	0.10	0.01	0.02	0.01	0.02	0.09	0.02

Table 14. Continued

Time (min)	Home-based work					Home-based non-work				
	All	Walk	Bike	Transit	Drive	All	Walk	Bike	Transit	Drive
100	0.02	0.00	0.01	0.09	0.01	0.02	0.01	0.02	0.09	0.01
101	0.02	0.00	0.01	0.09	0.01	0.02	0.01	0.02	0.09	0.01
102	0.02	0.00	0.01	0.09	0.01	0.02	0.01	0.02	0.09	0.01
103	0.02	0.00	0.01	0.09	0.01	0.02	0.01	0.02	0.09	0.01
104	0.02	0.00	0.01	0.09	0.01	0.02	0.01	0.02	0.09	0.01
105	0.01	0.00	0.00	0.07	0.01	0.01	0.01	0.02	0.07	0.01
106	0.01	0.00	0.00	0.07	0.01	0.01	0.01	0.02	0.07	0.01
107	0.01	0.00	0.00	0.07	0.01	0.01	0.01	0.02	0.07	0.01
108	0.01	0.00	0.00	0.07	0.01	0.01	0.01	0.02	0.07	0.01
109	0.01	0.00	0.00	0.07	0.01	0.01	0.01	0.02	0.07	0.01
110	0.01	0.00	0.00	0.06	0.01	0.01	0.01	0.01	0.07	0.01
111	0.01	0.00	0.00	0.06	0.01	0.01	0.01	0.01	0.07	0.01
112	0.01	0.00	0.00	0.06	0.01	0.01	0.01	0.01	0.07	0.01
113	0.01	0.00	0.00	0.06	0.01	0.01	0.01	0.01	0.07	0.01
114	0.01	0.00	0.00	0.06	0.01	0.01	0.01	0.01	0.07	0.01
115	0.01	0.00	0.00	0.05	0.01	0.01	0.01	0.01	0.07	0.01
116	0.01	0.00	0.00	0.05	0.01	0.01	0.01	0.01	0.06	0.01
117	0.01	0.00	0.00	0.05	0.01	0.01	0.01	0.01	0.06	0.01
118	0.01	0.00	0.00	0.05	0.01	0.01	0.01	0.01	0.06	0.01
119	0.01	0.00	0.00	0.05	0.01	0.01	0.01	0.01	0.06	0.01
120	0.01	0.00	0.00	0.03	0.01	0.01	0.00	0.01	0.05	0.01