COMMITTEE OF THE TRANSPORT ACCESS MANUAL

TRANSPORT ACCESS MANUAL:

A GUIDE FOR MEASURING CONNECTION BETWEEN PEOPLE AND PLACES

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The cover shows 45-Minute Accessibility by Transit in Sydney, from the report *Access across Australia (2019)*.

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Acknowledgments

Authors and Contributors to this Manual are given on the final page of the document.

1
Concepts

What's the point of transport?

Transport aims to connect people with goods, services, and activities. The places and activities people seek via transport include schools, jobs, shops, restaurants, hospitals, health care, concerts, social gatherings, parks, nature trails, and so on. Transport also enables packages or food deliveries to reach the individuals who ordered them. This definition recognizes a wider range of transport problems and potential improvements than analysts typically consider. For example, it recognizes problems such as the mobility needs of non-drivers, and therefore the importance of affordable and inclusive transport modes that don't require a driver's license. It also recognizes ways that land use patterns affect the distances people must travel and the travel options available. Therefore, this definition of transport recognizes the transport benefits of more compact and multimodal communities. This broader approach can be described as a shift from mobility- to access-oriented transport planning and engineering.

Access[1] refers to people's ability to reach goods, services, and activities. Physical movement – or what we call mobility – plays a role, but access also considers not just people's mobility but other factors affecting their capability to access opportunities, and the location of the opportunities, places, patterns of land use, as well as a host of other factors such as the quality and affordability of transport options and peoples' ability to use those transport options. If somebody has good access, they can easily reach the places they need to go, which can be true even if the nearby streets are congested and have low speeds. Alternatively, somebody can live right next to a major, uncongested thoroughfare but still have low access if the destinations they need to reach are distant or disconnected.[2]

[1] Here, and in much of the literature, the nouns *access* and *accessibility* are used interchangeably.

[2] Relatedly, the term *access management* refers to regulating the ability to enter local streets and driveways from major roads, thereby reducing the friction on the higher level roads, aiming to improve mobility and safety for other road users (Gluck and Lorenz 2010).

This *Manual* is a guide for quantifying and evaluating access for anybody interested in truly understanding how to measure the performance of transport and land use configurations. It contains enough to help transport and planning professionals achieve a more comprehensive look at their city or region than traditional transport analysis allows. It provides a point of entry for interested members of the public as well as practitioners by being organized in a logical and straightforward way.

While there are a number of great books and papers out there about access,[3] this *Transport Access Manual* intends to provide practitioners and other interested parties with a place to start. The structure is non-linear, akin to a hypertext, so you probably don't need to read the whole *Manual* in sequence. Start here, and use the Table of Contents to guide you. Your next step will depend upon how much knowledge you have on this topic to begin with but also what brought you here. You may be interested in the ability of major metropolitan areas to reach other cities across the globe; or, you may be interested in the access of your next apartment to neighborhood amenities; or more likely, you may be interested in something in between. No matter the case, this *Manual* is here to help.

3 Appendix H lists additional resources.

So why do we need this? What can measuring access do for us? What problems can it help us solve? To begin with, access can help us answer:

- Which groups have below or above average transport access?
- How well does my city's transit system help workers reach jobs?[4]
- Is my business located to attract a favorable employee pool?
- Which neighborhoods have better or worse entertainment and restaurant options nearby?
- How many students can walk or bike to a prospective school location?
- Do I have a hospital within 30 minutes ambulance ride?
- Can firefighters reach my house in 12 minutes?

4 The term *transit* is equivalent to the term *public transport*.

Access measures expand our set of possible solutions, because access sees movement as a means, not an end. The end is the ability to participate in the intended activity of the traveler.[5]

5 See section 1.5.

1.1 *Access and Mobility: Clearing Up the Confusion*

There is a lot of confusion – even among engineers and planners – when it comes to understanding what the terms *mobility* and *access* mean and how exactly they differ.

For the purposes of this *Manual*, *mobility* is about the *movement* of people and goods from here to there. In other words, how far can someone travel in a given amount of time? This is intuitively how many users perceive trip-making, from a first-person perspective. *Access*, on the other hand, is about what *places* someone can reach in that time. How many goods or services or destinations or social interactions can be accessed in a given amount of time?

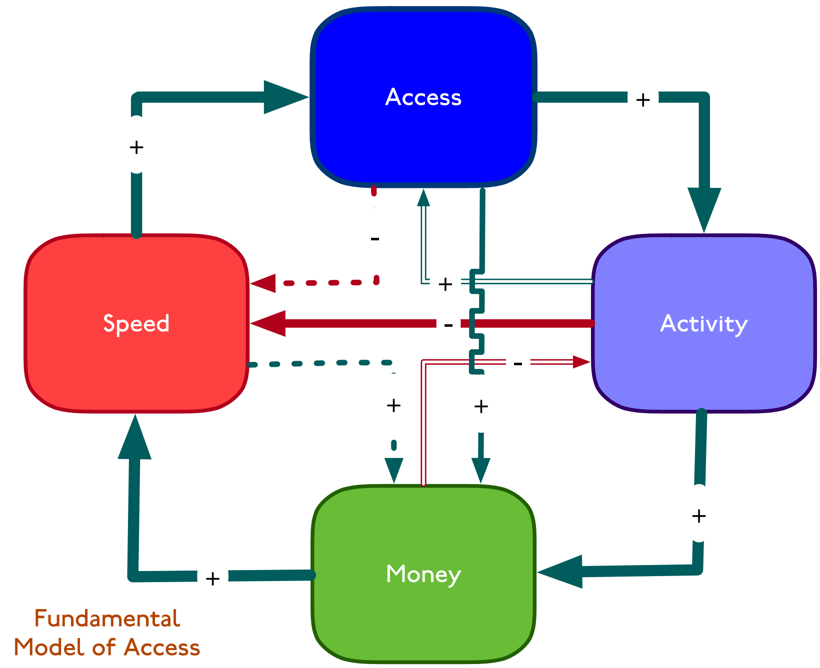
The American Association of State and Highway Transportation Officials' (AASHTO) *A Policy on the Geometric Design of Streets and Highways*, (AASHTO 2018). colloquially known as the *Green Book*, serves as the United States' primary guide for street and highway design and uses the concept of *mobility* and *access* to define the two axes of the functional classification system describing the hierarchy of roads. Their thinking is that roads have two basic functions: mobility and access. Mobility means that the road moves traffic; access means that the road allows access to the adjacent land. The underlying concept of the functional classification system is that bigger roads, like arterials, are supposed to have high mobility and low access while smaller local roads are intended to have low mobility and high access. Under AASHTO's definition, it does not matter what the land use is; it just matters that a driver can park there. Our definition is not the same as AASHTO's. We are not just concerned with the access of vehicles to parcels, but of different people to a diversity of places.

Another source of confusion for the concept of access is the idea of being able to access the transport system itself. Transport planners often ask: "How many people live within 10 minutes of a bus stop?" They are asking whether or not people can access the public transit system. However, few people are seeking to ride buses for their own sake; rather, they are seeking to go to a place of interest to them. Bus stops and train stations can be viewed and analyzed as destinations, but they are not the most important destinations. In this *Manual*, we do not focus on people's ability to reach parts of the transport system. Rather, we focus on the ability of people to reach places of interest to them.

New York City isn't exactly known for wide open roads with what would be considered high mobility (except in car commercials). Their most recent *Mobility Report* finds that the average speed of Midtown Manhattan vehicle traffic is less than 8 km/h (5 mph) (NYC DOT 2018). So someone starting in Midtown and driving half an hour probably won't go far. However, the number of places that she can access, starting in Midtown and given 30 minutes, is large. This is a place with high access and relatively low mobility.

At the other end of the spectrum, consider a traveler starting off in a place like Laramie, Wyoming. In a half an hour she can cover a lot of ground, but the number of destinations she can reach is a small fraction of what she could in Manhattan. New York City famously has over 350 different pizza places. Laramie seems to have fewer than a dozen. It's not just about pizza; there are more options on the job market and even more possibilities in the friendship or love department.

Figure 1.1: Fundamental Model of Access



1.2 *Fundamental Model of Access*

Figure 1.1 provides way of thinking about how transport networks ('*Speed*'), land use and travel demand activity systems ('*Activity*'), and the financial system ('*Money*') interact with *Access*. While this *Fundamental Model of Access* is obviously a simplification, like a good model, it clarifies understanding.

The main flow of the system is the green positive feedback loop. More begets more. More Activity generates more Money. More Money funds more infrastructure and increases travel Speed. Higher Speeds increase Access. More Access produces more Activity. This is shown by the outer connections on the diagram.

The inside of the diagram is a bit more complicated.

The central top to bottom (green) line (with hops) is a positive feedback from Access to Money. Creating access of itself will generate revenue (which can be captured with some sort of land value capture),[6] as people will pay a premium to be in a location with more opportunities available (because those opportunities represent some improved quality of destinations), separate from the premium to reach the same opportunities faster (because they have alternate uses of time), and separate from the revenue generated by the additional activities themselves (such as additional economic exchange).

[6] (Medda 2012).

In the upper right quadrant is another positive feedback loop, from Activity to Access. The more people there are in a place, the more people who can be reached by others, the higher the access.

In the lower left quadrant is the final positive feedback loop, from Speed to Money. The faster travelers are going, the more they are willing to pay (people pay a premium for faster travel),[7] in theory because they can use the time saved from not traveling to do something else (or in the long run, to relocate to a better location with more space, and transform the speed gains to a longer distance and lower land prices).

[7] (Owen et al. 2014).

If these were the only relations, cities would be solely a positive feedback system, and would converge to a single point in space, but they do not because there are some dampeners in the system.

The central right to left (red) line is a negative feedback from Activity to Speed. This represents the negative externalities of crowding and congestion. The more people there are, the slower a given infrastructure will be. More people on the road creates traffic congestion. More people on the bus slows bus boardings and alightings.

The lower right has a red negative feedback connection from Money to Activity. The more expensive something is, the less that is consumed. Here if we make travel or land development more expensive, we get less of that.

The upper left has the final negative feedback connection from Access to Speed. While Speed increases Access, Access decreases Speed. This is not due to crowding *per se* (which is represented by the horizontal line from Activity to Speed), but because of the frictions of locating in a place that provides access. Think of an urban freeway, even if it is not crowded, it is still slower than a rural freeway because it has a lower design speed, it has more curves as it was retrofit into an existing built-up urban environment, it has more exit and entrance ramps, and in general is slower because of the constraints of locating in a high Access area. The same is true of trains, buses, bikes, and even walking. Walking in a city with traffic lights on every block, even if there is little traffic, still is slower than walking in an environment without potential conflicts.

1.3 Access, Movement, and Place

How should we think about the transport problem? Figure 1.2 shows the physical relationship between access, movement, and place. It also illustrates the idea of the 10-, 15-, or 20-minute neighborhood.

Movement (or mobility) is defined by people's ability to move through space. We often measure this ability via time. The figure differentiates modes by color: yellow indicates walking (including trips in wheelchair and with strollers), green is bike, orange is bus, blue is train, and purple is automobile. Different activities can be reached in different amounts of time by different modes. Some modes are faster, and thus allow a broader activity space than others, people can reach more things in less time with the faster modes.[8] Speed of travel depends on road design and traffic levels. Distance depends on network directness or circuity. But mobility also recognizes the monetary cost of travel with respect to income. It should account for what people know or perceive about the network, and so depends on information and perception.

[8] Recall that $D = R \cdot T$, where D= distance, R=rate or speed, and T = time. Thus $T = D/R$ and is the ratio of distance traveled over speed of travel.

Place measures the location, kind, and intensity of activities (opportunities) available. The figure shows and places, services, and activities in black. Sometimes we refer to this same concept via the terms *land use*, i.e. the pattern of activities that occur across the landscape, or *destinations*.

So in the figure, for instance, a basketball court can be reached in 10 minutes by walking, while a regional park can be reached in 20 minutes by bicycle, and a hospital in 10 minutes by bus from the origin. The dashed lines indicate the isochrones, lines of equal travel time from the origin, in this case 10, 20, and 30 minutes by walking. As can be seen, the bicyclist can go in 10 minutes as far as it takes 20 minutes to walk.

In terms of the provision of transport, what matters isn't how fast people move, it's about how many things they can reach. Start by asking yourself how we can connect people with the places they want to go. Mobility – and moving people quickly – is a part of the answer, but it's also about place, proximity, and land use. We have the ability to arrange our cities and regions so that people can quickly and easily get to the places they need to go. If we do that right, what we typically measure to assess mobility within our transport system – such as speed and traffic congestion – are not nearly as important. What do we measure instead? The answer is access, and this *Manual* will help you measure it.

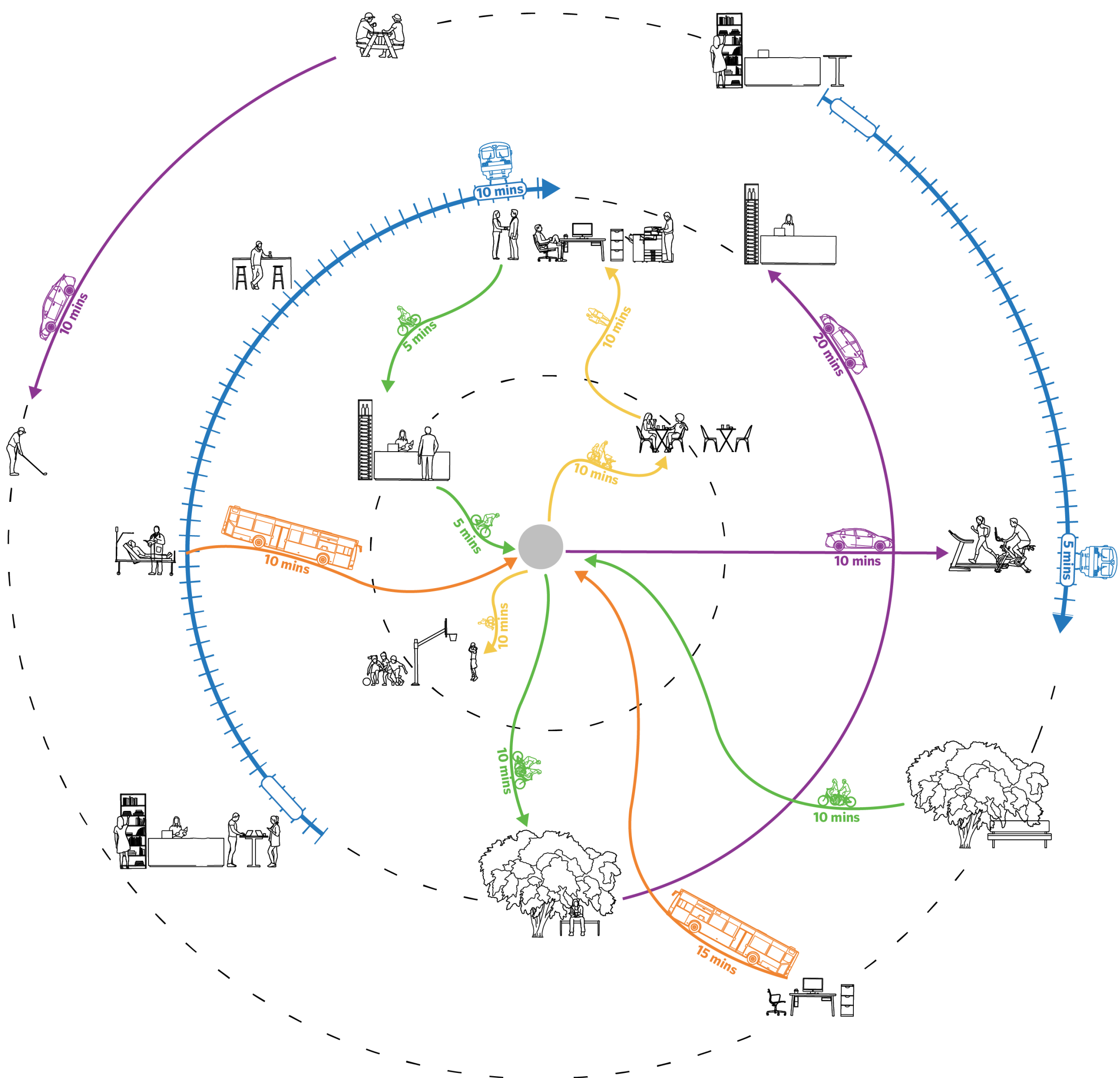


Figure 1.2: Access, Movement, and Place.

1.4 Access and Equity

When responding to concerns about meeting the needs of disadvantaged groups, or enacting policies that rectify injustice that they have experienced, policy-makers often think they are addressing equity when they equitably distribute a certain tool (rail lines, bus rapid transit, paratransit, microtransit, various technology pilots, etc) without regard to whether that tool actually addresses the problems of each community or group. The tool that maximizes access for one place or group of people may not do so for others, so it doesn't make sense to think of equity solely as the fair distribution of each tool.

Instead, when thinking about transport in an equity context, people should ask themselves what exactly should be distributed equitably, and should consider whether the answer is *access*. For example, when studying a transport system, it is possible to count how many jobs, or other useful destinations, each resident can reach in 45 or 60 minutes, and/or at a certain cost. Then, where census data is available, it's possible to calculate whether people in disadvantaged or historically marginalized groups – based, for example, on race, ethnicity, caste, income, age, disability, etc. – experience better or worse access than the whole population. If it's worse, there's a potential equity problem.

In particular, mobility and accessibility have different implications for people with disabilities.[9] Mobility refers to the ability to move, and if somebody has a mobility impairment, they may not move freely and/or easily. *Accessibility* in this context refers to design solutions intended for people with such mobility constraints, such as wheelchair users.[10] Accessibility for people with disabilities is part of the broader concept of access. But in this *Manual*, while we are concerned with the access of people with disabilities, we take a universal perspective – all people's access is of concern when evaluating a transport system. Access here concerns the ability of all people to reach their destinations. Sometimes we focus on particular high-need groups, but at other times we generalize to a broad notion of the general public, while recognizing that designs intended to solve problems for people with physical constraints may be better designs for everyone.

[9] (Grisé et al. 2019).

[10] More generally, see the idea of Universal Design (Story 1998).

If desired, further analysis can then be devoted to whether the source of the problem is spatial inequality (the disadvantaged group just lives further from the places they need to go than the dominant group does) or purely a matter of inequitable transport (even where they don't live further from destinations than the dominant group, they experience inferior access to opportunity because they rely on slower and less reliable modes of travel.) This helps identify the limits of what transport policy, without the support of spatial development policy, can be expected to address.

For certain groups, other forms of impedance may also matter apart from total travel time or cost experienced by travelers without those constraints. Most obviously, some physically disabled people have a different experience of what everyone else calls 'walking,' and access analysis for them may need to account for physical barriers that impede only them (see e.g. Figure 6.1). The geography of personal safety may also matter, especially where crime or harassment are an issue, and for groups disproportionately susceptible to those problems.

When transport equity questions are framed in this way, as being about equitably distributing access to opportunity, it becomes easier to select the right kind of intervention, be it relocation of activities or modification of transport infrastructure and service for each community, based on what will actually be more liberating for them.

Access Factors	Improvement Options
Mobility	Improve traffic speed, capacity and safety by paving roads and improving roadway design
Mobility options	Improve walking, bicycling, ride-hailing, taxi, automobile, car-sharing, carpooling, and public transport
Prioritization	Facility management and pricing favor higher-value trips and more efficient modes
Mobility Substitutes	Improve telecommunications and delivery services that substitute for physical travel
Network connectivity	Increase the density of paths and roads, and the connections between modes
Proximity	Increase density and mix to reduce travel distances and improve walkability
Affordability	Improve affordable access options (walking, cycling, ride sharing, transit, and tele-work)
Convenience	Improve user information and payment systems

Table 1.1: Selected Access Improvement Strategies. Source: (Rode et al. 2017).

Perspectives	Short Run	Long Run
Individual	What destinations can I reach with my limited money and time?	Where should I choose to live and work?
Businesses	What customer pool is readily able to reach our location?	Where should we locate to maximize profits (by making it less expensive for customers, vendors, and employees to reach us)?
Real Estate	What rents can I charge?	Where should we build to maximize rents (due to access)?
Traffic Engineers	What traffic signal strategies improve mobility and access for all users?	What road designs will minimize future transport problems and maximize access?
Transit Analysts	What service changes increase access?	What capital projects maximize access?
Urban Planners	How can we arrange land uses to increase access?	What land use policies will minimize future transport problems and maximize access?

Table 1.2: Access Perspectives

1.5 *Strategies for Access*

In general, access is desirable, so planners often focus on access improvement strategies such as those shown in Table 1.1.

While it might seem easy to select approaches and work towards moving in the right direction, it is worth pointing out that conflicts often arise between different access factors. For example, more compact development increases proximity, but, by increasing congestion, simultaneously reduces mobility by car and bus. Another example is hierarchical street networks. While they tend to increase traffic speeds, they also reduce connectivity and proximity compared with more compact and connected street networks. Thus, it is important to ensure we understand what we are proposing and to think through the various, and sometimes competing, implications of any intervention. Increasing access by one mode often creates barriers for those using another.

The questions we ask ourselves with regard to measuring access also depend upon our perspective. Sometimes it is an individual, short-term concern of where one can go today, sometimes it the long-term issue of where one should live and work. Sometimes it is a business concern of trying to attract customers or employees to the current business location, and sometimes it means considering where a business could re-locate to in order to maximize its ability to attract customers and employees. Planners also need to consider the system as a whole. Table 1.2 describes these perspectives as well as the related short and long-term concerns.

These perspectives also relate to some of the broader implications of access. When it comes to affordability, for instance, it is important to consider the interdependence of housing cost and location. A less expensive house may not truly be affordable if it is located in an isolated areas with higher transport costs. In turn, it might make sense for a household to pay more for a house located in an accessible neighborhood that helps reduce transport costs.

This *Manual* does not prescribe particular alternative tactics or strategies, though it does identify some that communities have used. Instead it focuses on how to test the effectiveness of those alternatives.

1.6 *Roadmap for Using this Manual*

In the next chapter[11] example applications and use cases for access are shown. The *Manual* then puts you on a path where your measures[12] are comparable to those of other people using this *Manual*. It provides step-by-step guidance for calculating access.[13] It identifies additional factors you may want to consider, other than travel time and commuting trips. It also highlights common methodological issues[14] and how to resolve them. It then discusses what sort of data[15] you will need to get started as well as what sort of data would be ideal.

The *Manual* concludes by identifying topics that are emerging in the domain of access analysis, as new modes, delivery, and telecommunications become increasingly relevant.[16]

The first appendix discusses the consequences of access, why access matters to the rest of the economy.[17] The next appendix covers ways to integrate access into planning processes.[18] This includes discussion of how to integrate access into a new generation of collaborative planning. It next overviews alternative access metrics and tools.[19] The *Manual* then delves into how to manage an access team and tool.[20] A sample Request for Proposal for an access platform is provided.[21] Finally, a selection of Further Reading is given.[22]

If any of the above intrigues you, you have come to the right place.

[11] See chapter 2.
[12] See chapter 3.
[13] See chapter 4.
[14] See chapter 5.
[15] See chapter 6.
[16] See chapter 7.
[17] See appendix A.
[18] See appendix B.
[19] See appendices C and D.
[20] See Appendix F.
[21] See appendix G.
[22] See Appendix H.

2
Uses

Access metrics are useful in a broad range of contexts. Because they integrate effects of land use and transport, they are widely used in transport, service delivery, planning, real estate, and land development with metrics that have evolved over more than a century. Because they quantify the lived experience of transport, they are useful in long-range planning and performance monitoring. Because different groups may not experience the same levels of access, access metrics are also useful for analyzing the equity of the transport and land use system.

This chapter presents real-world examples of access metrics being used in many different contexts. These examples demonstrate the breadth of access metrics and their applications, and provide tangible examples of the measures that will be detailed in subsequent chapters. These examples aim to help you understand the breadth of applications of access metrics and inspire you to apply access in your own work. They include:

- Baseline Trend Analysis (section 2.1).
- Performance Monitoring (section 2.2).
- Performance Standards (section 2.3).
- Goals (section 2.4).
- Transport Project Evaluation (section 2.5).
- Land Development Evaluation (section 2.6).
- Disadvantaged Populations (section 2.7).
- Transport Equity (section 2.8).
- Financial Costs (section 2.9).
- Travel Behaviour (section 2.10).

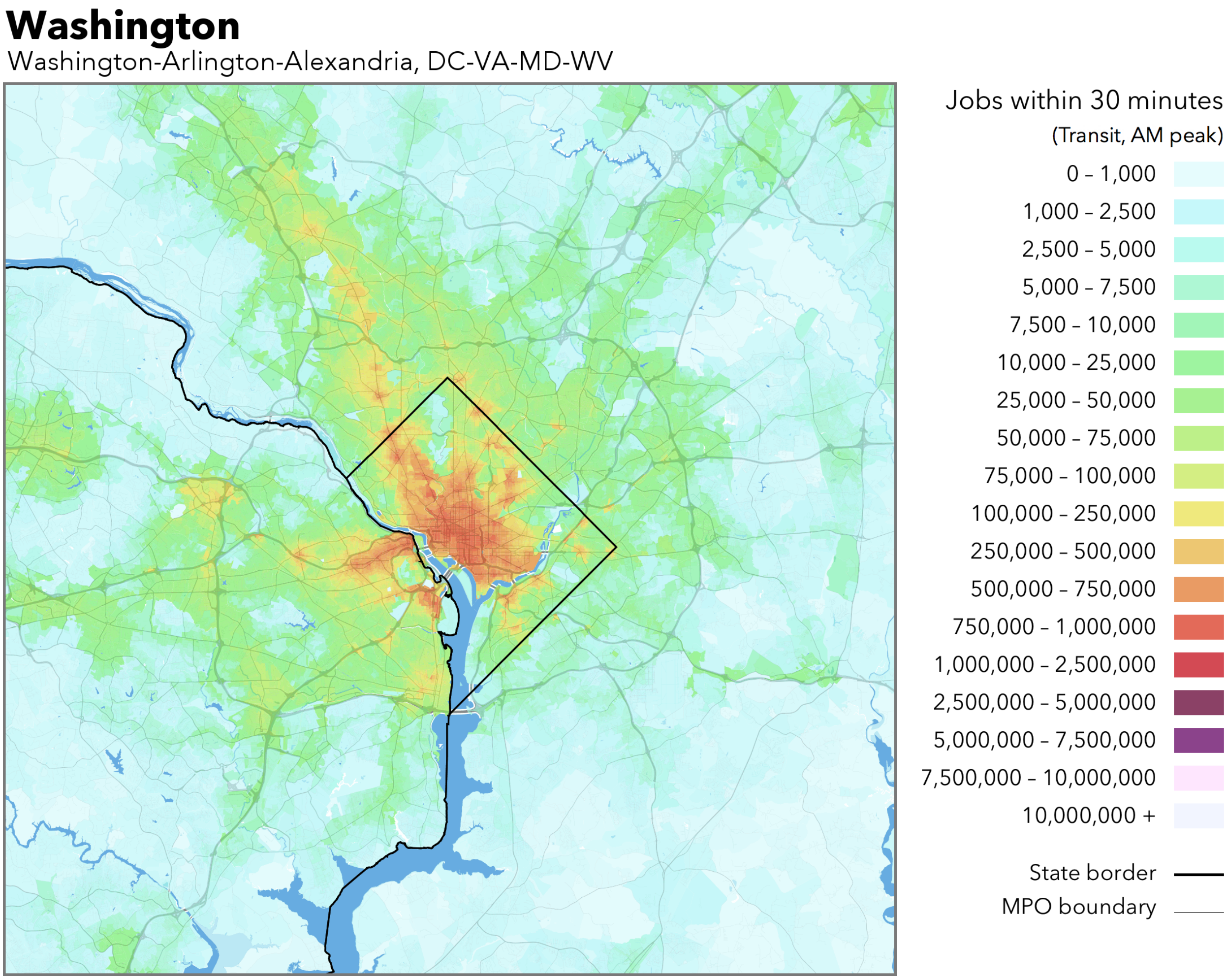


Figure 2.1: Access to Jobs via Transit, Washington, DC. (Accessibility Observatory 2017).

2.1 *Baseline Trend Analysis*

The first question before using access for evaluation is: 'What is the baseline?' The baseline is essential to establish what is going on before any changes. It is also useful for comparing changes over time, such as in trend analysis and comparing between places.

The baseline nearly always lies in the historical data series used to measure access. Planning for school locations has long considered the acceptability of travel time and travel arrangements as part of social policies that require education. Many countries have similar requirements for other public and private services using access metrics to define the quantity and quality of opportunities available. By the middle of the 20th century many countries were also starting to formalise standards of access to jobs and services such as the deprivation indices in the UK.[1]

Towards the end of the 20^{th} century some countries developed national access statistics to monitor change in standards of access over time, such as the German access indicators in federal development plans,[2] or the Spanish indicators used for prioritising investment in regional development.[3]

By the start of the 21^{st} century some form of access indicators were established in either law, or practice or both in many developed countries but the rigor with which the transport system was described left substantial scope for improvement. In the 21^{st} century, theory and practice of access trend analysis was able to exploit growing availability of data and modern GIS systems.

For instance, the Accessibility Observatory at the University of Minnesota[4] produces annual data, maps, and reports on access to jobs by transit, driving, walking, and cycling in the United States. Access to jobs via transit in Washington, DC is shown in Figure 2.1.[5] Standardized maps are produced for metropolitan areas across the US, facilitating comparisons.

The baseline from which changes are considered is particularly important because in practice it is the changes in access that are most important for policy. Some people choose to live in inaccessible areas, while others choose to live in accessible places, and a major concern for policy is how the effects of economic and social trends and public investment are distributed geographically and socially. A key feature of the Accessibility Observatory's reports is a ranking of the relative access afforded to residents between and within different metropolitan areas of the US. In the 2018 release, New York had the top job access by transit, while Los Angeles had the highest job access by auto.[6] These national access rankings allow planners to compare metros in terms of how well they provide access to residents. Changes in rankings over time allow one to track the relative performance of the transport and land use systems in various cities, and understand which cities are top performers. This study has been replicated in Australia and New Zealand.[7]

The International Transport Forum (ITF) undertook a similar project to evaluate differences in access across Europe.[8] Rather than measuring access to jobs as the Access Across America reports do, ITF measures access to a variety of other opportunities including schools, hospitals, and food stores.

The ITF report also carefully considers how best to make access metrics comparable across places of different size. Naturally a large

[1] English UK Government Indices of Deprivation.

[2] (Birkmann 2003).

[3] (López et al. 2008).

[4] (Accessibility Observatory 2017).

[5] Note that this figure shows a cumulative opportunity measure. The calculation of such measures is discussed in 3.1.1.

[6] (Owen and Murphy 2020a;b).

[7] (Wu and Levinson 2019; 2020).

[8] (International Transport Forum 2019a).

city may have a higher absolute number of opportunities accessible than a smaller city, simply because there are more opportunities in that city. Conversely, a larger percentage of the opportunities in a small city may be accessible to the average resident, because most or all of the city is within a short distance.

Given the breadth of the opportunities considered, access is used to evaluate in which cities a number of objectives are best met, such as ability of children to travel independently to school, or ability of residents to cycle to parks. These metrics taken together help planners understand how the transport and land use system in cities across Europe contributes to the quality of life in those cities, and understand where improvements can be made.

In a similar vein, the Australian Urban Observatory measures access to local destinations in urban centres across Australia.[9] It maps access to different types of opportunities, including social infrastructure, food, public open space, and employment.[10] It also combines different metrics into an index of walkability. Measures are estimated at the suburb (neighborhood) level, with aggregation across Local Government Areas (LGAs) and cities also available.

[9] (Australian Urban Observatory 2020).

[10] The access baseline and comparison tool provides an example of access applied to inform policies on a wide range of societal issues, including identification of disparities in the health, sustainability and social opportunities across Australia's urban centres.

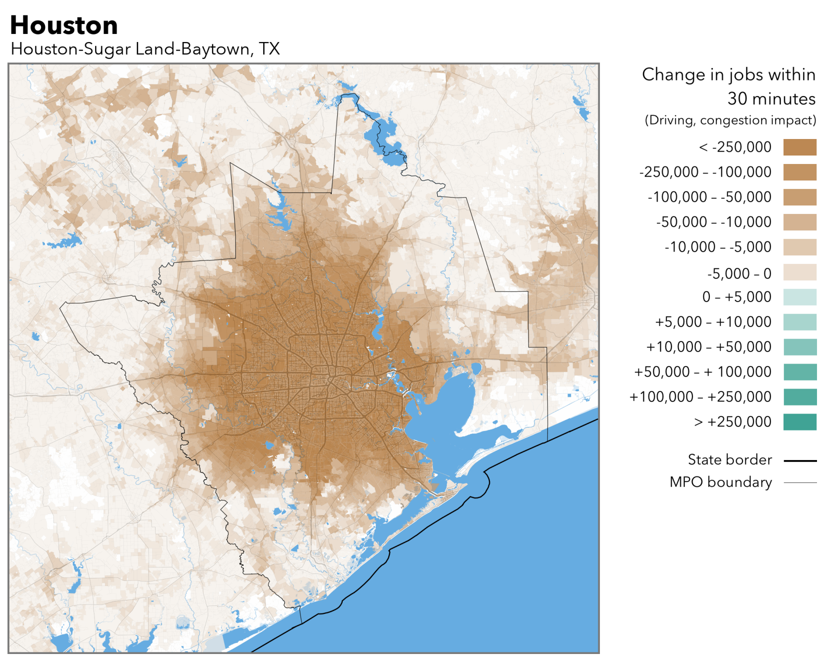


Figure 2.2: Access by Auto in Congested Conditions vs. Free-flow, Houston. (Accessibility Observatory 2017).

San Francisco
San Francisco-Oakland-Fremont, CA

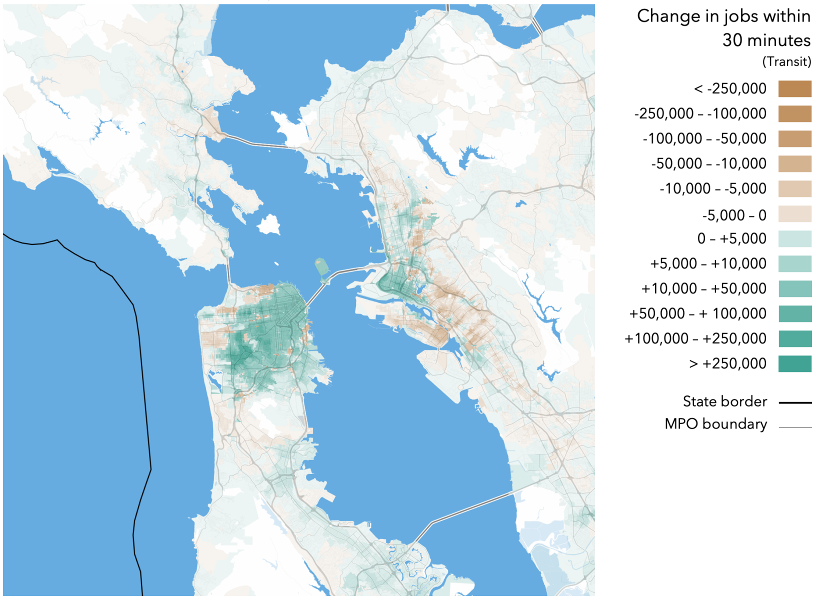


Figure 2.3: Change in Transit Access, San Francisco, 2016–2017. (Accessibility Observatory 2017).

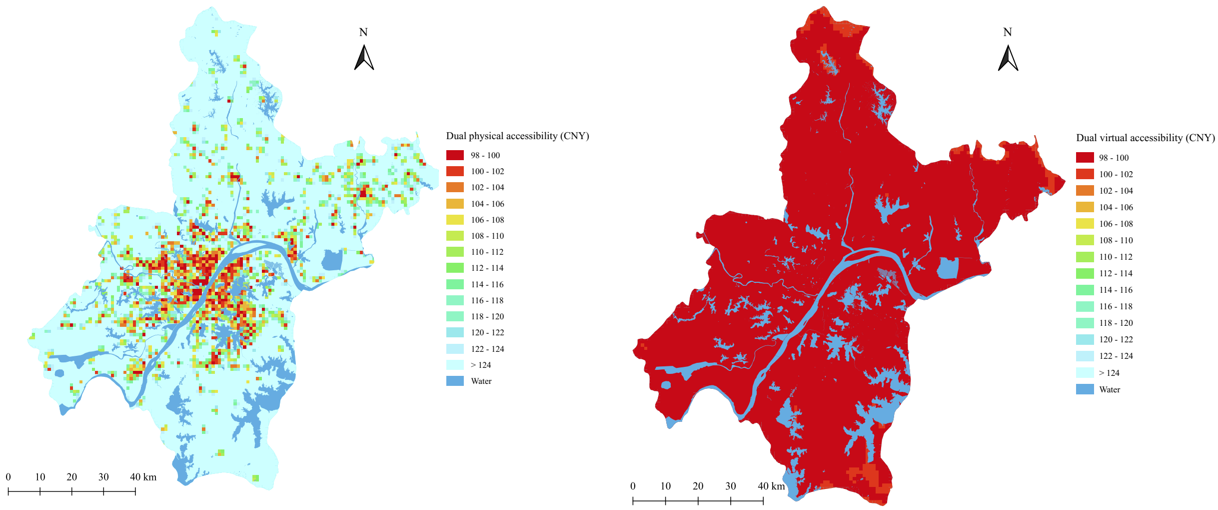
2.2 *Performance Monitoring*

Access metrics can be used to monitor the performance of the transport system. For instance, the Accessibility Observatory at the University of Minnesota uses access metrics to understand the impact of congestion on auto access by comparing peak-hour access to the maximum access achieved at any time of day.[11] Figure 2.2, comparing access at 8:00 am versus the free-flow conditions overnight, shows that in Houston, congestion significantly reduces job access by auto. The largest losses are in inner suburbs, where commutes to job centers are long enough that relatively move these commutes from under to over 30 minutes. This effect of large impacts on access from changes in transport system performance in inner suburbs has been termed the "ring of unreliability."[12]

[11] (Owen and Murphy 2020b).

[12] (Cui and Levinson 2018a).

Access metrics can also be compared over time to understand trends in system performance. Figure 2.3 shows how access to jobs via transit changed in the San Francisco area from 2016–2017. Access generally improved in the central city, while more suburban areas saw declines in access. Such geographic summaries of access change help planners track differing access outcomes, and decide whether transport or land use changes are warranted to maintain desired levels of access.



(a) Physical Access. (b) Virtual Access.

Figure 2.4: Physical and Virtual Grocery Store Access in Wuhan, China. Source: (Chen et al. 2020).

2.3 *Performance Standards*

Many people start thinking about access standards from the perspective of physical access for those with mobility difficulties, but access standards can relate to any attribute of people, places, or connections.

Performance standards establish a minimum quality of service.[13] There are *performance standards* for public services such as schools, libraries, parks, police, and fire.

- FIRE - A common fire standard says that 90% of residents should be within 4-minute response time for fires.[14]

- POLICE - The New South Wales (Australia) police have similarly set a statewide target that they will respond to 80% of urgent calls within 12 minutes.[15] A shorter response time decreases risk, but is more costly to provide.

- RECREATION - The American Society of Planning Officials published *Standards for Outdoor Recreation Areas* in 1965.[16]

These standards may vary by location, even within a jurisdiction, so rural areas have slower police and fire response times, because the risk may be viewed as less critical (fewer people would be affected). In this case the *valued destination* of access analysis is people's homes.

[13] A *performance standard* is sometimes called an *orthostandard* to avoid confusion with alternative meanings of the word *standard*, in particularly the idea of compatibility. The meter is a standard measure of distance. Everyone agrees on its definition. This *Manual*, for instance, establishes how to measure 30-minute cumulative opportunities to jobs as one standardized measure of access.

[14] The international non-profit called the National Fire Protection Association (NFPA) guideline (NFPA 1710) recommends a travel time of four minutes or less for 90% of fire and medical emergency incidents.

[15] New South Wales Police Annual Report.

[16] (American Society of Planning Officials and Moeller 1965).

2.4 Goals

While a *performance standard* is typically established by some formal, often professional organization, and adopted locally, access *goals* don't have the imprimatur of external validation, and are locally established. There is no universal performance standard for an acceptable level of access to destinations provided by the market, such as jobs or shops. There is no agreed-upon rule which says that in 30 minutes people should be able to reach at least 150,000 jobs, or that people should be able to access 50 restaurants in no more than 15 minutes.

A number of cities have long-range plans that aim for all or most residents to be able to access all of their basic needs by non-motorized transport within a short walk or bike ride of their home. Sydney, for example, has divided itself into three '30-minute cities,' with the nearest major business districts available within a 30-minute trip by walk, bike, or public transport, where residents can be largely self-sufficient.[17]

[17] (Greater Sydney Commission 2018, Levinson 2019).

The 20-minute neighborhood or 30-minute city is an access concept.[18] To be a 20-minute neighborhood means that residents have *access* to all of the things they need for daily living within a 20-minute walk or bike ride.[19] The 20-minute neighborhood is related to the time-denominated or dual access measures, discussed in section 3.2. This is further discussed in subsection 2.4.1.

[18] (Levinson 2019).

[19] Often this 20-minutes refers to a round-trip, so might be better thought of as a 10-minute neighborhood.

The use of access as a metric means that these goals are concrete and measurable. Specific quantitative targets can be set, and analyses can be repeated in the future after changes to land use and the transport network have occurred. For instance, Portland, Oregon reported that they had moved from 63% of residents living in 'complete neighborhoods' in 2010 to 65% in 2016, where complete neighborhoods are closely related to 20-minute neighborhoods.[20] While this is a small improvement, it is a measurable change towards their goals. Without a quantitative access metric, it would be difficult to accurately quantify progress towards a more connected and accessible city.

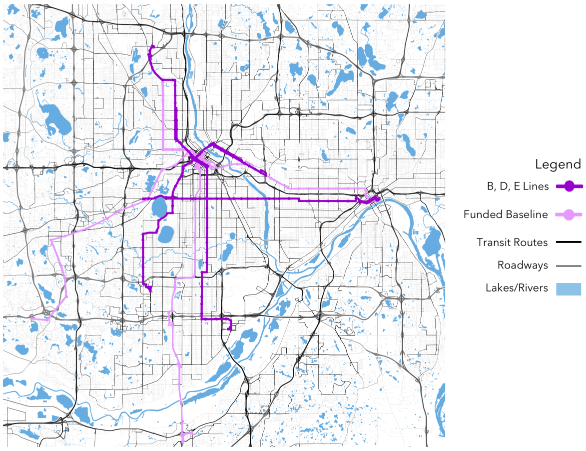
[20] (City of Portland, Oregon 2017).

2.4.1 The Pint-of-Milk Test – Access to Everyday Necessities

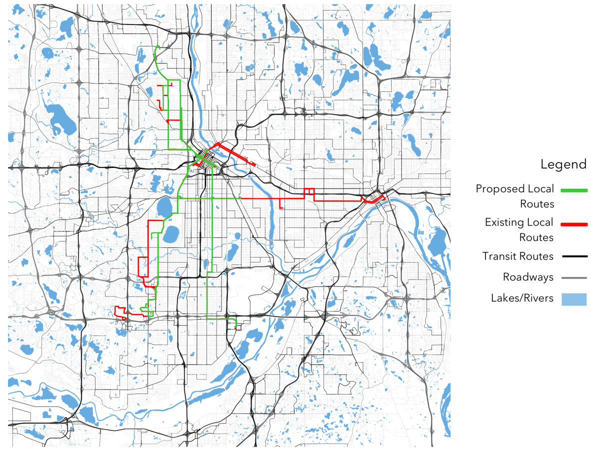
The '20-minute neighborhood' suggests residents should be able to get to daily activities, like buying a pint-of-milk, within a round trip of 20 minutes (10 minutes each way) by walking. Extensions to this include the 'pint-of-beer' test, where beer is the beverage of interest. Another version asks if you can get your milk at a store that doesn't also sell petroleum, in other words, is it an actual corner shop, or a likely less attractive experience of a fuel retailer (servo) with a built-in convenience store. Examples of these tests include:

- 5 - Copenhagen is looking at a '5-minute city' to achieve carbon-neutrality (Peters 2019).
- 10 - Satisfying the 'pint-of-milk' test asks whether you can purchase a pint-of-milk within a 10-minute walk of your home (Crawford 2009).
- 15 - Ottawa is proposing a '15-minute neighborhood' (CBC News 2019).
- 20 - The related '20-minute neighborhood' is based on the concept of 'living locally' by giving residents the opportunity to access all the services they need with a 20-minute walk, cycle or public transport trip.The 20-minute walk is often expressed as a round-trip, making it equivalent to the 10-minute neighborhood using a one-way definition.
  - Twenty-minute neighborhoods feature in Plan Melbourne (Topsfield 2019).
  - Portland, Oregon's Climate Action Plan calls for 90% of residents to be able to easily walk less than 20 minutes to meet non-work needs including grocery stores, restaurants, and transit (City of Portland Bureau of Planning and Sustainability and Multnomah County Sustainability Program 2009).
  - Tempe, Arizona has set a similar 20-minute city goal, but has evaluated bicycle and transit access as well as pedestrian access. Tempe has additionally considered that cycling and walking may be constrained by the quality of the pedestrian or bicycle infrastructure (Capasso da Silva et al. 2019).

An illustration of the pint-of-milk test compares access to grocery stores using a dual (in this case, cost-denominated) access measure (section 3.2) for Wuhan, China, is shown in Figure 2.4. The total individual cost of in-person grocery shopping is compared with online grocery delivery. Instead of setting a threshold number of shopping venues as potential destinations, this study uses the 'completion of a grocery shopping task' as the threshold, and measures the combined time and monetary cost for completing this task, including time to travel to and from the store and time in store, and cost of groceries, in the case of physical access, and the time spent online, the delivery waiting time, and the cost of goods for the virtual access case. Weights are required to translate the time for various elements to a monetary cost. In Wuhan, depending on the values of time, the total cost to receive groceries from delivery is generally lower than the total cost of going shopping.



(a) May 2019, Funded Baseline, and Prospective Transit Routes.



(b) Existing and Proposed Local Routes in the Funded Baseline and Prospective Network.

Figure 2.5: Proposed Changes to the May 2019 Network and Funded Baseline in Minneapolis and St. Paul, Minnesota.

2.5 *Transport Project Evaluation*

Analysts typically compare access from some alternative scenario (a new development, a new facility, a new schedule) with access from the baseline, and see how access changes. Communities may have policies to ensure access improves (does not worsen) overall, or for certain population groups.

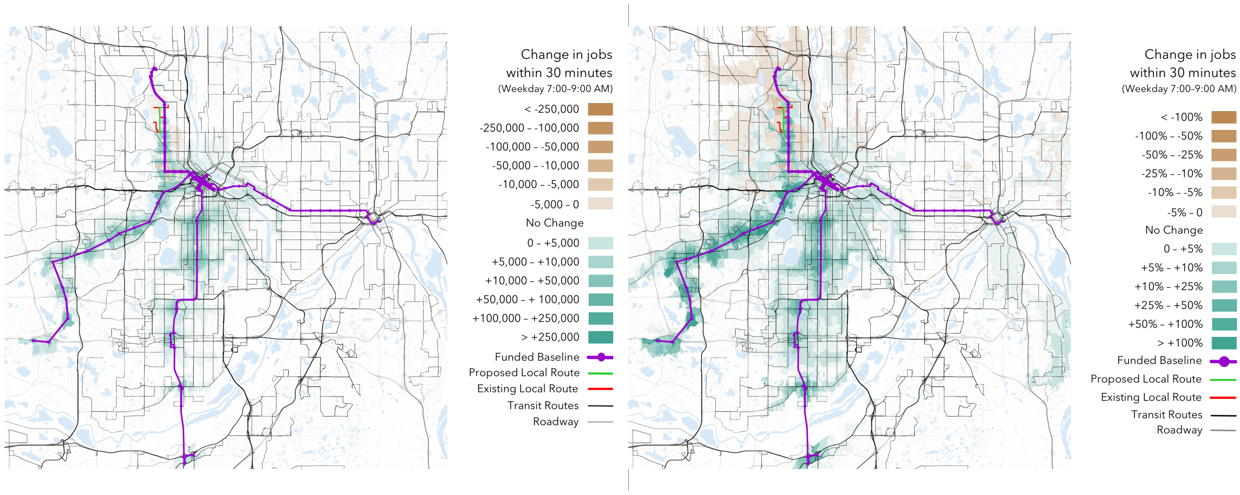
Transport system investments can be evaluated by measuring access before and after a proposed implementation. This example evaluates rapid bus lines in the Minneapolis - St. Paul region.[21] It extends previous access analyses of the Green Line LRT and A Line Rapid Bus.[22]

In total, six routes were evaluated over four time periods, weekday 7:00 am – 9:00 am, weekday 11:00 am – 1:00 pm, weekday 4:00 pm – 6:00 pm, and weekend 11:00 am – 1:00 pm. Figure 2.5 shows the six selected transitways and the local routes that were modified to reflect new high frequency service in the transitway corridors.

The evaluations were approached in stages. The first stage calculated job access using the transit network at the time of the evaluations, May 2019. This was used as the first baseline for analysis. The second stage revised the May 2019 baseline by adding three transitways that were funded and undergoing construction at the time of the analysis. This *Funded Baseline* scenario routes included:

[21] This analysis was conducted by the Accessibility Observatory, in partnership with the Metropolitan Council in Minneapolis – St. Paul, Minnesota.

[22] (Owen and Kadziolka 2015, Palmateer et al. 2016).



(a) Absolute change. (b) Percent change.

Figure 2.6: Change in Number of Jobs Accessible between May 2019 Baseline and Funded Baseline, 7:00 – 9:00 am, 30-minute Travel Time Threshold

- C Line – Arterial Rapid Bus on Penn Avenue from North Minneapolis to downtown Minneapolis
- Green Line Extension – LRT extension from downtown Minneapolis to suburban Eden Prairie
- Orange Line – Highway BRT along Interstate 35W south of Minneapolis to suburban Lakeville

Census block level access was calculated for the May 2019 baseline and the Funded Baseline. The change in access is found by taking the difference between the two scenarios. The results are shown in Figure 2.6. The change is largely positive for the area shown.

ACCESS INCREASES ARE DUE TO:

- increased frequency along existing transit corridors,
- increased speed,
- new service where previously there had been none, or
- network effects in areas where local service coordinates well with the upgraded corridor.

ACCESS DECREASES ARE DUE TO:

- reduced local service frequency,
- changes in local stop locations, or
- transfers that are no longer coordinated between the upgraded corridor and existing local service.

In addition to producing maps of access change, an average access change across the metropolitan area was produced, weighted by the

	15 min	30 min	45 min	60 min	Time-weighted
May 2019 Baseline vs Funded Baseline	+6 (+0.27%)	+518 (+1.22%)	+2,824 (+2.31%)	+7,523 (+3.72%)	+210 (+2.29%)
Funded Baseline vs Prospective Network	+245 (+5.91%)	+3,532 (+7.80%)	+8,847 (+5.66%)	+13,394 (+4.18%)	+784 (+5.51%)
D Line	+194 (+5.10%)	+2,681 (+6.40%)	+6,271 (+4.42%)	+9,404 (+3.15%)	+575 (+4.28%)
B Line	+29 (+0.35%)	+513 (+0.68%)	+1,584 (+0.61%)	+2,648 (+0.59%)	+129 (+0.65%)
E Line	+24 (+0.45%)	+390 (+0.60%)	+1,177 (+0.58%)	+1,721 (+0.49%)	+94 (+0.57%)

Table 2.1: The average worker-weighted absolute (percent) access to jobs change at four travel time thresholds and the time-weighted measure for the Metropolitan Council jurisdiction, weekday 7:00 – 9:00 am.

worker population. This was repeated for a selection of travel time thresholds, as well as an average across multiple thresholds with shorter travels times weighted more heavily as shown in Table 2.1.

Access can be measured and compared across different stages in planning if the right stakeholders are involved with guidance and data procurement. The Metropolitan Council played a critical role in determining how the evaluations should be staged, and Metro Transit provided the necessary data. The partnership allowed the results from this analysis to align with the planning process and increase the chances of this work holding value into the future.

2.6 *Land Use Change Evaluation*

Since access measures interactions between the transport and land use systems, access metrics can be used to investigate changes to land use as well as changes to transport. As shown in Figure 2.7, evaluating access in Minneapolis - St. Paul, Minnesota, under different scenarios for future land use and transport systems, researchers separated out the effects of land use and transport, making it easy to isolate the effects of particular land use changes on access to opportunities, and determined that concentrated population growth in the core led to the largest increases in access.[23] Disaggregating the effects of land use change and transport system change on access to jobs via car in the Netherlands, researchers found that changes in land use produce a large increase in access during the study period, but these are almost completely offset by increased congestion.[24]

[23] (Anderson et al. 2013).

[24] (Geurs et al. 2003).

Since we often think of travel as being a derived demand, derived from the desire to engage in activities which take place at places, land use is the key motivator for travel demand. Being able to evaluate land use changes using the same tools that we use to evaluate transport is invaluable. When access targets are included in long-range plans, these goals implicitly reflect not only changes to transport networks, but also changes to land use patterns.

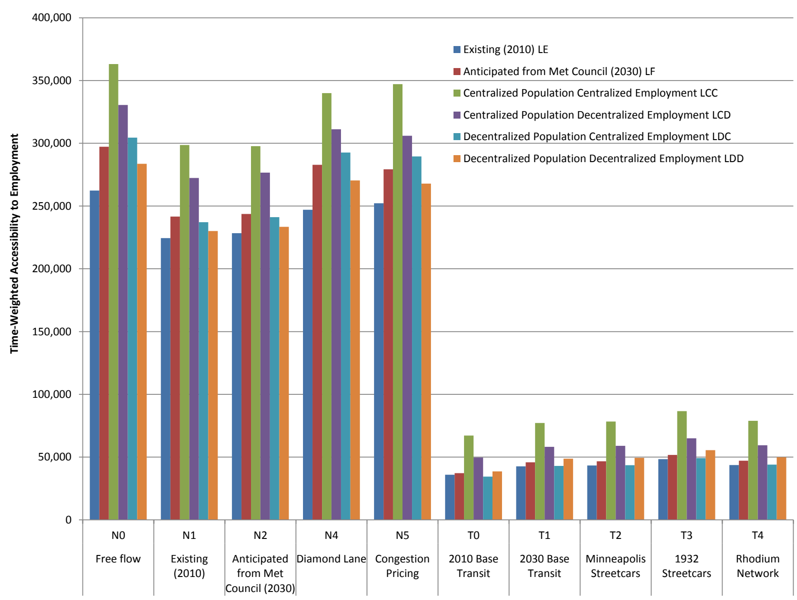


Figure 2.7: Future Person-weighted Accessibility to Jobs in Minneapolis - St. Paul Region under Network and Land Use Scenarios. (Anderson et al. 2013).

2.7 *Metrics for Disadvantaged Populations*

Many places set goals to improve social equity, social inclusion and population wellbeing in their long-range plans. Access metrics support planners in the quantification of these goals through the development of objectives and indicators. For example, Transport for London, with the objective of improving social inclusion, measured access to employment from deprived areas, defined as the percentage of the population in the 10% most deprived areas of London within 45 minutes travel time of international and metropolitan centers.[25] Similarly, the New South Wales Government aimed to reduce social disadvantage by improving access to destinations, including goods, services, employment and education opportunities, across the entire State.[26] Access maps were developed both for public transport and private vehicles to identify gaps in access. Adopting a broader perspective, the Greater Manchester Combined Authority developed access objectives to support the achievement of social goals such as improving population wellbeing and reducing health inequalities. Proposed objectives included improving the level of access to healthcare facilities, for specific populations, namely the elderly and people with disabilities, and to open greenspaces and sport facilities for targeted communities.[27]

[25] (Transport for London 2006).

[26] (Transport for NSW 2013).

[27] (Hyder Consulting and Greater Manchester Integrated Transport Authority 2010).

Disaggregating access metrics and accounting for affordability by demographics allows planners to measure whether the transport and land use system are providing equitable access to opportunities. This approach is common in the United States, where Metropolitan Planning Organizations (MPO) are required by law to conduct an environmental justice assessment. Using access metrics, planners typically compare the level of access to opportunities for different population groups and assess whether some populations suffer disproportionate negative impacts.

The North Central Texas Council of Governments compared the percent change of a series of job access metrics for protected (disadvantaged) and non-protected populations. The protected population groups are identified based on race and income. As an example, Table 2.2 presents the access metrics for Black and non-Black population. The same tables were created for low-income populations, American Indian/Alaskan Native, Asian, Native Hawaiian/Pacific Islander races as well as Hispanic ethnicity. Disaggregating access metrics in this way allows understanding whether access is equitably distributed, and how transport projects will impact equity.

Table 2.2: Job Access by Race in the Dallas metropolitan area. Modified from (North Central Texas Council of Governments 2015: Appendix B).

Population	2017 Network	2040 No-Build	2040 Build	2040 Change
Number of Jobs Accessible within 0-30 Minutes by Auto				
Black	618,467	426,044	625,788	46.9%
Non-Black	580,547	325,140	501,679	54.3%
Difference	37,920	100,904	124,109	
Number of Jobs Accessible within 0-30 Minutes by Transit				
Black	238,592	201,892	371,088	83.8%
Non-Black	167,841	128,042	247,980	93.7%
Difference	70,751	73,850	123,109	
Number of Jobs Accessible within Walking Distance (2 miles)				
Black	10,438	15,973	16,059	0.5%
Non-Black	9,489	11,899	11,932	0.3%
Difference	948	4,075	4,127	

In this example, the protected population actually lives in areas with higher access than the non-protected population. This finding is not uncommon, but inequities are more present when accounting for differential rates of vehicle ownership between groups – auto access is generally higher than public transit access, but is only relevant for those who own autos, so a suburbanite with a car can reach more jobs than a center city resident without one.[28]

[28] (Grengs 2012). See also section 4.2.

Measurements of equity can also be sensitive to how the metric is defined. After implementation of a bus rapid transit system in Rio de Janeiro, researchers showed the effects of the project depended on how the access metric was defined; when access to opportunities within a relatively short travel time was considered, the project benefited lower income residents most.[29] However, when longer travel times were considered, the project benefited groups more equally.

[29] (Pereira 2019).

2.8 *Transport Equity Analysis*

> Equity in transportation seeks fairness in mobility and access to meet the needs of all community members. A central goal of transportation equity is to facilitate social and economic opportunities by providing equitable levels of access to affordable and reliable transportation options based on the needs of the populations being served, particularly populations that are traditionally underserved. This population group includes individuals in at least one of the following categories: Low Income, Minority, Elderly, Children, Limited English Proficiency, or Persons with Disabilities. – (Federal Highway Administration 2019).

Equity analysis informs and supports spatial planning goals that aim to ensure employment, social, and health opportunities are distributed equitably (Lowe et al. 2015). Access analysis should form the quantitative backbone of transport equity analysis. However, it is not the only step. Public engagement is essential for understanding barriers to equitable access and to co-design appropriate solutions (Twaddell and Zgoda 2020). The methods described in this *Manual* provide inputs and measures that can help identify gaps in coverage and underserved populations for subsequent consultation. This step is documented in section 2.1. Quantitative approaches outlined in this *Manual* are also important for evaluating the access afforded by different project alternatives (section 2.5), to monitor the performance of an intervention against desired outcomes once delivered (section 2.2), and to compare the access afforded to different subpopulations (section 2.7).

Multiple access measures should be used in equity analysis (Martens 2016). Broad population measures for different activities and modes may be appropriate for identifying underserved populations, however barriers related to individual differences may be less suited to population measures, and should focus on measures of particular sub-groups, or even of individuals.

2.9 *Financial Costs of Access*

Motor vehicle transport is costly. It is typically the second largest expense in most household budgets, after housing, and a major financial burden to many lower-income families, particularly if the family car breaks down unexpectedly or is involved in a crash. High levels of access may only be available to those who own vehicles, Providing affordable, multimodal access as an alternative to vehicle ownership is thus a key transport equity concern.

Modal decisions often involve trade-offs between time and money costs. For instance, driving may save time but cost the individual in gas, vehicle maintenance, annual fees, and health care issues related to physical inactivity. Meanwhile using transit and walking part of the distance may take more time but cost less in transit fares, as well as in producing fewer externalities.[30] Similarly, households often make trade-offs between cheaper housing in more isolated, automobile-dependent areas, or paying more to live in an accessible, multimodal location where transport costs, including time and money, are lower.

[30] Externalities are costs not borne by parties to an economic transaction (the traveler and transport agency) and include things such as pollution. See (Cui and Levinson 2018b).

Time itself is valued differently across individuals and is another aspect of overall travel choice. How time is valued is tied to many personal attributes, primarily income relative to competing living costs.

While many access metrics are based on travel time, access metrics can include monetary cost as well, which is important as lower-income populations may not be able to afford to access the fastest transport.[31]

[31] (El-Geneidy et al. 2016).

Access metrics can include both private and social costs as well as travel time for social evaluation, where environmental and other externalities are important.[32]

[32] (Cui and Levinson 2019).

Applying an access metric based on both travel time and transit fare to a scenario lowering fares at inner stations on the Boston commuter rail system, researchers found that lowering fares could yield a large increase in access for budget-constrained travelers who currently rely on lower-cost but slower bus and subway systems, without any changes to service.[33] Similar research commissioned by TransitCenter quantified increased access to jobs for budget-constrained New York City commuters, under scenarios with fare reductions and service additions (Figure 2.8).

[33] (Conway and Stewart 2019).

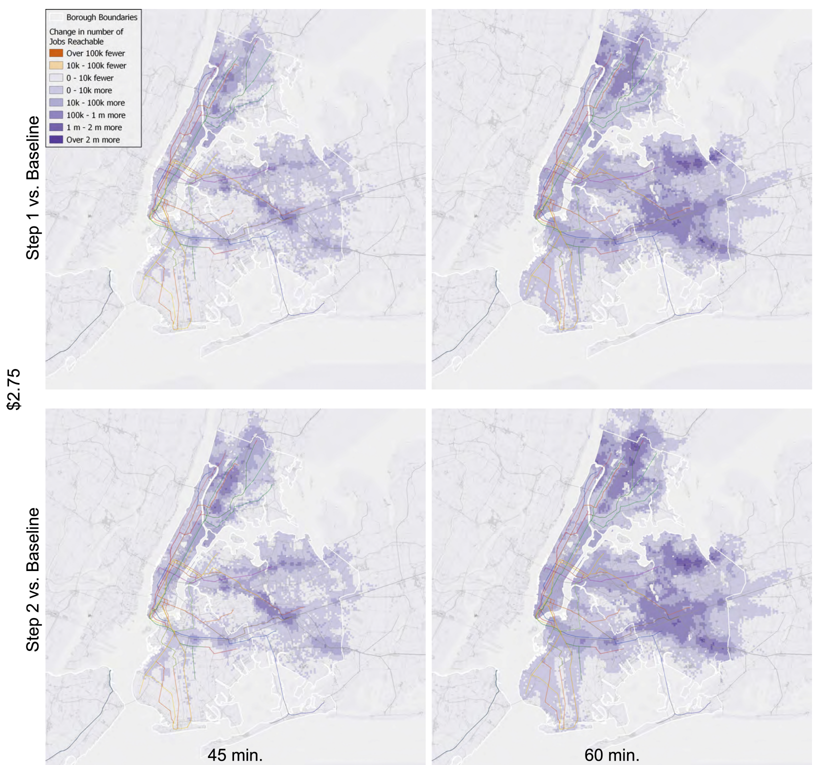


Figure 2.8: Changes in Access Due to Fare Policy and Service. Increases in access to jobs, given a $2.75 limit on fare cost and 45- and 60-minute limits on door-to-door travel time, with incremental fare reductions (Step 1, reducing commuter rail fares in New York City to $2.75) and service additions (Step 2, increasing commuter rail frequency). Source: TransitCenter.

2.10 Predictor of Travel Behavior

Access is an important predictor of travel behavior. Trips of people who live in high access areas tend to be shorter because nearby options are available.[34]

[34] (Levinson 1998).

The relative access from a given location via different modes is often a helpful predictor of mode share. Areas with high transit access relative to auto access are more likely to have a high transit mode share, for example [35] Likewise, areas of high pedestrian access are likely to have more pedestrian trips.

[35] (Owen and Levinson 2015, Wu et al. 2019).

For this reason, access metrics are often included in the strategic planning models used by metropolitan planning organizations to forecast future travel demand. For example, consider the open source, activity-based UrbanSim/ActivitySim model system, designed to model long- and short-term changes to urban development and travel behavior. This model framework calculates access within the model simulation process, and uses it to forecast how households and developers will make decisions.[36] Access indicators have been used both within strategic transport planning model systems, [37] and distinctly as an 'access-based' travel demand model by transport planning organizations.[38] Access indicators are useful not only as a final output of analysis, but as an intermediate output that can be used to forecast behavior in a feedback system.

[36] (Waddell et al. 2018).

[37] (Ewing et al. 1996).

[38] (Bernardin Jr 2008).

3 Measures

Accessibility measures can be broadly grouped into two categories:[1]

- PRIMAL MEASURES,[2] such as cumulative opportunities, are *opportunity-denominated*, they examine how many opportunities can be reached in a given amount of time (cost).

- DUAL MEASURES[3] are *time*- or *cost-denominated* and consider how long it takes (how much it costs) to reach a given set of opportunities.

Roughly speaking, primal measures describe the breadth of opportunity available, while dual measures describe the cost of traveling to some set of specific opportunities.

This chapter also discusses the advantages and disadvantages of each type of access measure.

[1] (Cui and Levinson 2020).

[2] section 3.1.

[3] section 3.2.

3.1 *Primal Measures: Opportunity-Denominated Access*

An early description of the concept of potential, or opportunity for interaction, was in Carey's (1867) the *Principles of Social Science*.[4] Walter Hansen used this concept to describe access to opportunities and defined "accessibility" as "the potential of opportunities for interaction."[5]

What has come to be known as the *Hansen equation* (Equation 3.1) has been used to measure access to different opportunities including jobs,[6] retail services,[7] and other people.[8]

$$A_i = \sum_j O_j f(C_{ij}) \tag{3.1}$$

Where:

A_i: access from location i.

O_j: number of opportunities available at destination j.

C_{ij}: cost of travel from i to j.

$f(C_{ij})$: impedance function.

Three kinds of primal (opportunity) measures are discussed here:

- CUMULATIVE OPPORTUNITIES MEASURES[9] count the number of opportunities within a *travelshed*.[10]
- WEIGHTED CUMULATIVE OPPORTUNITIES MEASURES[11] value closer opportunities more heavily than distant opportunities.
- COMPETITIVE MEASURES[12] account for the effect of competition among travelers for a limited set of opportunities.

4 (Carey 1867).

5 (Hansen 1959).

6 (Linneker and Spence 1992).

7 (Guy 1983).

8 (Patton and Clark 1970).

9 subsection 3.1.1.

10 A *travelshed* is equivalent to the area enclosed by an *isochrone*, and refers to an area whose boundary is a given travel time from the origin.

11 subsection 3.1.2.

12 subsection 3.1.3.

3.1.1 *Cumulative Opportunities Measures*

Cumulative opportunities measures count the number of potential opportunities that can be reached within a certain distance, time, or other costs. For cumulative opportunities measures, the impedance function $f()$ from Equation 3.1 is given by Equation 3.2, taking on the value 1 if travel time is less than some threshold t and 0 otherwise:[13]

$$f(C_{ij}) = 1 \text{ if } C_{ij} \leq t, \text{ else } f(C_{ij}) = 0 \tag{3.2}$$

[13] A $[1,0]$ dichotomy is sometimes referred to as a *binary* or *indicator* function.

Advantages.

- Cumulative opportunities measures require relatively minimal data.
- The concept of what is reachable within a certain travel time is understood by most non-specialists. Cumulative opportunities measures are usually comprehended by decision-making boards composed of people who are not transport experts.
- The results of a given cumulative opportunities measure hold a consistent meaning across different times and places, enabling greater comparison, tracking, and benchmarking.

Disadvantages.

- *Cumulative opportunities measures* use a single cutoff travel time to determine whether a particular opportunity is reachable. This can cause edge effects when a large cluster of destinations (for instance, a major office building) is just beyond the cutoff time.[14] For example, if opportunities of interest are largely concentrated in a single area, a strict 45-minute cutoff would lead to higher access for places 44 minutes away from this area but lower access for places 46 minutes away. Additionally, the choice of cutoff time can affect the ranking of places by relative access.[15] However, in most practical cases, the edge effects are minor and a cumulative opportunities measure offers an accurate picture of access. The arbitrariness of any particular cutoff threshold can be mitigated by examining a range of thresholds. It is straight-forward to report results for multiple thresholds.[16]
- There is no obvious standard[17] for the right number of opportunities that should be accessible. Typically the desired target for cumulative opportunities reachable is determined through comparison across places, contexts, or times.

[14] Edge effects are discussed in section 5.1.

[15] (Pereira 2019).

[16] For instance, once an access analysis is underway, it is trivial to report 5-, 10-, 15-, 20-, 25-, 30-, 35-, 40-, 45-, 50-, 55-, and 60-minute thresholds. Travel time thresholds are often anchored to observed travel behaviors and/or round numbers, such as (15, 30, 45, and 60 minutes) for travel times to work.

[17] See section 2.3.

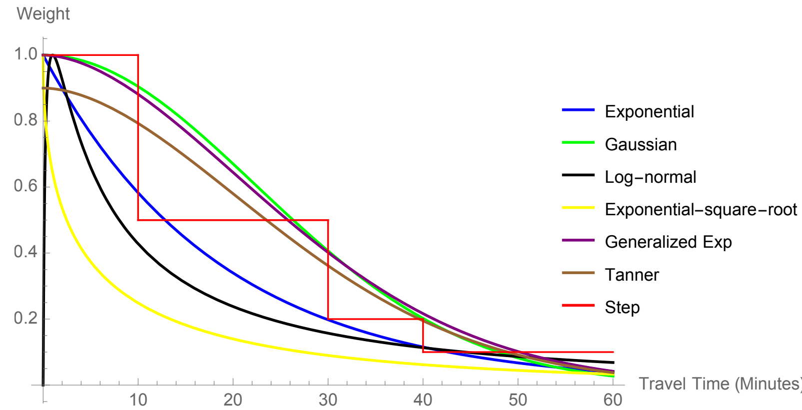


Figure 3.1: Common Impedance Functions

3.1.2 *Weighted Cumulative Opportunities Measures*

Weighted cumulative opportunities measures (or *gravity*)[18] measure discounts opportunities based on their travel distance, time, and/or cost, rather than using strict cutoffs. These 'impedance' functions[19] recognize that the value of an opportunity is lower if it is costlier to reach.

A variety of impedance functions are possible. Figure 3.1 shows the shape of common impedance functions. Common practice is to use functions estimated in the destination choice (or trip distribution) component of a strategic planning model.[20] The one requirement is that impedance must be a decreasing[21] function of time. Thus, we can think of such measures as *weighted* cumulative opportunities where nearby opportunities are weighted more heavily than distant ones.

The most commonly used form for the impedance function is the negative exponential shown in Equation 3.3, where a value of $\beta < 0$ must be determined.

$$f(C_{ij}) = e^{\beta C_{ij}} \tag{3.3}$$

Some have argued that the negative exponential impedance function better represents human behavior.[22] But it worth recognising that many other impedance functions are also possible, as shown in Table 3.1 and each have adherents.[23]

For the negative exponential formulation of impedance, a travel time of zero minutes results in full weighting ($f(C_{ij}{=}0) = 1$), so therefore negative exponential measures can be considered as the

[18] The earliest impedance functions were based upon Newton's law of gravity, wherein the strength of an attraction decreased with the square of distance. Therefore, these measures have historically been called 'gravity-type' measures.

[19] These functions are historically referred to as 'distance decay functions.' Since we now consider time and other costs, analysts prefer the more general term 'impedance'.

[20] *Strategic planning models* are also referred to as *urban (or regional or metropolitan) transportation planning models*, *travel demand models*, or *four-step models*.

[21] More accurately, impedance must be non-increasing.

[22] (Handy and Niemeier 1997, Wilson 1971).

[23] (Feldman et al. 2012, Geurs and Van Wee 2004, Reggiani et al. 2011).

Function	Expression	At $C_{ij} = 0$ $f =$	Typical values α	β
Cum. Opportunities	if $C_{ij} \leq t, f(C_{ij}) = 1$ else $f(C_{ij}) = 0$	1		
Exponential	$f(C_{ij}) = e^{\beta C_{ij}}$	1		$-0.008^{\dagger}$, $-0.054^{\oplus}$
Exponential-normal	$f(C_{ij}) = e^{\beta C_{ij}^2}$	1		$-1.2 \cdot 10^{-5^{\dagger}}$,$-0.001^{\oplus}$
Exponential-square-root	$f(C_{ij}) = e^{\beta \sqrt{C_{ij}}}$	1		$-0.261^{\dagger}$,$-0.44^{\oplus}$
Generalized Exp.	$f(C_{ij}) = e^{\beta (C_{ij}^{\alpha})}$	1	$1.8^{\oplus}$	$-0.002^{\oplus}$
Power (Gravity)	$f(C_{ij}) = C_{ij}^{\alpha}$	0	$-1.835^{\dagger}$	
Tanner	$f(C_{ij}) = C_{ij}^{\alpha} \cdot e^{\beta C_{ij}}$	0	$-0.63\oplus$	$-0.5\oplus$
Log-normal	$f(C_{ij}) = e^{\beta \cdot ln^2(C_{ij})}$	undefined		$-0.178^{\dagger}$,$-0.16^{\oplus}$
Logistic	$f(C_{ij}) = 1 - \frac{1}{1+e^{-\kappa(C_{ij}-t_i)}}$	0.5*		

†: Observed trips: Reggiani et al. (2011)
⊕: Best model fit: Feldman et al. (2012), Wu et al. (2019)

The logistic impedance function is a reverse S-curve, centered on an inflection point t_i, that weights opportunities close to the origin by a factor close to 1, and opportunities far from the origin by a factor close to 0; 0.5*: $f = 0.5$ when $C_{ij} = t_i$.

Table 3.1: Alternative Impedance Function Expressions

equivalent of a certain number of opportunities immediately outside one's doorstep. This is called *effective opportunities*.

Weighted opportunity access measures are often presented in comparative rather than absolute terms, so their meaning has to be taken by comparing the access of one location to another. For easy comparison, it might be worth considering rescaling the measures to a range such as 0-100.[24]

[24] (Geurs and Van Wee 2004).

ADVANTAGES.

- Weighted cumulative opportunities measures consider the full range of travel times, rather than simply whether a travel time is above or below a cutoff. This more closely maps to human behavior. Travelers do value a destination 31 minutes away more highly than one 59 minutes away, and a destination 61 minutes away is only marginally worse than one 59 minutes away.

DISADVANTAGES.

- A key challenge in deploying a weighted cumulative opportunities measure is choosing an impedance function, and estimating associated parameters. Even with a relatively simple impedance function like the negative exponential (Equation 3.3), the values of β vary widely across contexts.[25]

  If the region in question has a strategic planning model with a destination choice (trip distribution) component, estimated values of β can be borrowed from that model.[26] Because people perceive the cost of travel time differently for different trip purposes,[27] by different modes, and at different times-of-day, different values of β would better reflect behavior. If the strategic planning model offers separate parameters for different trip purposes, these could be used.

  If no strategic planning model is available, developing an estimate of β specific to a particular regional context may be difficult. A simplified method has been proposed for calibrating β based on observed median travel times for a specific trip purpose, mode, and/or population.[28] Alternatively, if an origin-destination matrix is available to the analyst, they could fit a destination choice model to these data to derive β values appropriate for different trip purposes and modes for the region.[29]

  Also, if a destination choice model is available from a different, but similar region, it may be possible to borrow β estimates derived from that region. However, parameters vary between regions, so a good fit to local travel patterns is not guaranteed.[30] If the above techniques are not feasible, estimating this parameter may be prohibitive, suggesting that a cumulative opportunities measure should be used instead.

- A weighted cumulative opportunities measure is less interpretable than an unweighted cumulative opportunities measure. Whereas it is clear what a certain number of jobs within a certain number of minutes means, weighted cumulative opportunities measures may be more opaque.[31] The explanation and use of 'effective opportunities' as described above may assist.

- Weighted cumulative opportunities measures depend on the impedance formula used, and these formulas vary from place to place and time to time. Therefore, weighted cumulative opportunities measures are not meaningfully transferable across cities nor across years. There is no guarantee that the impedance coefficient of today will still be valid or relevant 10 years from now.

[25] (Haynes et al. 1984).

[26] (El-Geneidy and Levinson 2006).

[27] (Martínez and Viegas 2013).

[28] (Merlin 2020).

[29] (Papa and Coppola 2012).

[30] (McArthur et al. 2011).

[31] Like cumulative opportunities measures, weighted cumulative opportunities measures assume each destination of a particular type is fungible and offers the same level of attraction.

3.1.3 Competitive Access Measures

Both the cumulative opportunities measure and the weighted cumulative opportunities measure as presented above only consider the supply of opportunities. Many opportunities are rival, meaning that if person A fills an opportunity (such as a job), it is unavailable to person B. In cases where opportunities are rival, a *competitive access measure* may be suitable.

Consider two cases, access to parks and access to hospital beds in New York City. In the case of access to parks, parks are rarely full, and therefore a traditional or weighted cumulative opportunities measure might accurately capture the ability to access parks. Hospital beds, on the other hand, must be measured relative to the level of population. One can imagine a situation where a large number of hospital beds are available nearby but they are all occupied. In this case, an access measure should consider both supply and demand, and therefore a competitive measure should be used.

In particular, in the case of employment opportunity, only one candidate can fill each job opening. There is some evidence that employment opportunity is better measured by a competitive access measure than by a non-competitive measure,[32] in particular for lower-income populations.[33]

[32] (Shen 1998).

[33] (Merlin and Hu 2017a).

The method for calculating competitive access is to discount each supply-side opportunity by the amount of demand for that opportunity at its location. Equation 3.1 is extended as described below.

Competitive access is formulated as the ratio of opportunities reachable from a location, with those opportunities discounted by the level of demand that has potential access to such opportunities. It sums the 'supply to demand ratio' for each destination, subject to impedance functions. The destination-based access ratio differs from the origin-based measure, in accounting for the source of demand; opportunities at each destination are discounted by their corresponding demand. The basic formulation of demand-adjusted potential access is shown in Equation 3.4 - Equation 3.6.[34]

[34] Adapted from (Shen 1998).

1. Compute the access at the destination ($A_j^{\circlearrowleft}$) – say the workplace – to demand (D_i) – for instance, how many workers can reach the destination.

$$A_j^{\circlearrowleft} = \sum_{i=1}^{I} D_i f(C_{ji}) \tag{3.4}$$

2. Discount the number of opportunities at the destination j due to competition ($g(O_j)$) as:

$$g(O_j) = \frac{O_j}{A_j^{\circlearrowleft}} \tag{3.5}$$

3. Calculate access to jobs (A_i^g) considering competition as:

$$A_i^g = \sum_{j=1}^{J} g(O_j) f(C_{ij}) \tag{3.6}$$

Advantages.

- Competitive access measures account for competition among travelers or consumers for destinations. This more accurately represents access in situations where opportunities are constrained. Job opportunity may best be described by competitive access measures.[35]

- Competitive access measures require little more data than traditional or weighted cumulative opportunities measures. The formula for discounting by the intensity of demand works for both traditional and weighted cumulative opportunities formulations. If the total amount of demand and the total amount of supply are balanced within an analysis area, the average level of competitive access will be exactly 1.0.[36]

Disadvantages.

- Competitive access measures require more computation than cumulative opportunities measures.

- Competitive access measures are more difficult to interpret because they do not represent a tangible quantity but a ratio. Like weighted cumulative opportunities measures, they are interpreted in a comparative sense.

- A location with both many opportunities and high demand is not comparable to a place of few opportunities and minimal demand level in terms of access.[37] Accessibility experienced at these two locations would likely be very different, however, the competitive access ratio method would produce similar results for both locations.

If simpler measures provide the same degree of policy guidance as competitive measures, then simpler measures should be preferred.

[35] (Merlin and Hu 2017b). However note that jobs are generally more spatially concentrated than population, so the variation in A_i is greater than $A_j^{\circlearrowleft}$. At the extreme, if there is no variation in $A_j^{\circlearrowleft}$, A_i and A_i^g are equivalent.

[36] (Allen and Farber 2017). This means that locations with a competitive access measure above 1.0 have superior access whereas those with access below 1.0 are inferior with respect to this measure. This improves upon traditional job/worker balance measures, (Cervero 1989; 1996). as it is not limited to jurisdictional boundaries.

[37] (Knox 1978).

3.2 Dual Measures: Time-Denominated Access

The previous section of this chapter presents access as denominated by the *number* of opportunities reachable for a given travel time (or cost) threshold. This is how access is most commonly measured in both transport planning practice and in most academic literature. This section introduces the *dual access* measure, as denominated by the *time* required to reach a given number of opportunities.[38]

[38] Following the terminology of Cui and Levinson (2020).

We discuss two types of dual measure, the dual for a single opportunity and the dual for multiple opportunities.

3.2.1 Single Opportunity

The simplest application of the dual access can be found in the 'pint-of-milk' test,[39] one version of which asks if one can buy a pint-of-milk within a walk of 10 minutes from home. But the way we answer this is by finding out how many minutes it takes to get to the nearest shop selling milk. If the travel time is less than 10 minutes, the test is passed, else it is failed. In this example, the number of threshold opportunities is 1, (the question is binary, can you find one store selling milk), and access is measured by the travel time to the nearest store which sells that pint. When the threshold number of opportunities increases, additional computation may be required as described in subsection 3.2.2.

[39] See subsection 2.4.1.

In the case with 1 closest opportunity desired, the dual access can simply be computed by measuring travel time to all potential destinations, as shown by Equation 3.7, and finding the minimum of C_{ij} for all j where the opportunity can be found, represented mathematically as:

$$A_i' = min \begin{pmatrix} C_{i1} \\ C_{i2} \\ ... \\ C_{ij} \end{pmatrix} \forall j \qquad \text{such that} \qquad O_j > 0 \tag{3.7}$$

3.2.2 Multiple Opportunities

The case where more than one opportunity is sought is naturally more complicated. An intuitive understanding of the dual access measure for multiple opportunities is possible through the idea of the travelshed or travel time isochrone. In primal access, the size of isochrones (i.e. travel time) are fixed, and the number of opportunities enveloped within the isochrone serves as the access measure; in dual access, the isochrone keeps expanding, until a threshold number of opportunities are covered. The travel time for this 'expanded' isochrone serves as the access measure.

The dual access for multiple opportunities ($A_i^{'}$), is formulated as:

$$A_i^{'} = \widehat{Q_{ij}} C_{ij} \tag{3.8}$$

Where:

$\widehat{Q_{ij}}$ results from:[40]

[40] In mathematics, the term *argmin* identifies the elements of the domain of a function where the function values are minimized.

$$\widehat{Q_{ij}} = \underset{Q_{ij}}{\text{argmin}} \sum_{j=1}^{J} O_j Q_{ij} C_{ij} \tag{3.9}$$

subject to:

$$\sum_{j=1}^{J} O_j Q_{ij} \geq \Omega \tag{3.10}$$

$$Q_{ij} \in \{0, 1\} \tag{3.11}$$

Where:

$A_i^{'}$: dual accessibility of origin i;

Ω: opportunity threshold;

$\widehat{Q_{ij}}$: incidence matrix indicating the destination j that holds the nearest Ω^{th} opportunity for origin i.

Q_{ij}: cells in incidence matrix $\widehat{Q_{ij}}$:

'1' if destination j included in the set of destinations,

'0' otherwise.

Equation 3.8 through Equation 3.11 is a generic solution to calculating dual access. Here we provide an algorithmic procedure for calculating dual access for a specific location i, once the number of jobs in each location, and travel time between locations are known. Figure 3.2 shows the procedure in a flow chart.

A few things to note:

- $\mathbf{C_i}$ is a slice from the travel time matrix C_{ij}, that includes only travel times originating from location i to all other locations. Items in $\mathbf{C_i}$ are arranged in ascending order, from locations closest to location i, to the furthest (numbered from 1 to K, $K = J$, indexed by k).
- $\mathbf{O}$ has the same content as the jobs matrix, O_j, but re-ordered to have the same sequence as $\mathbf{C_i}$.

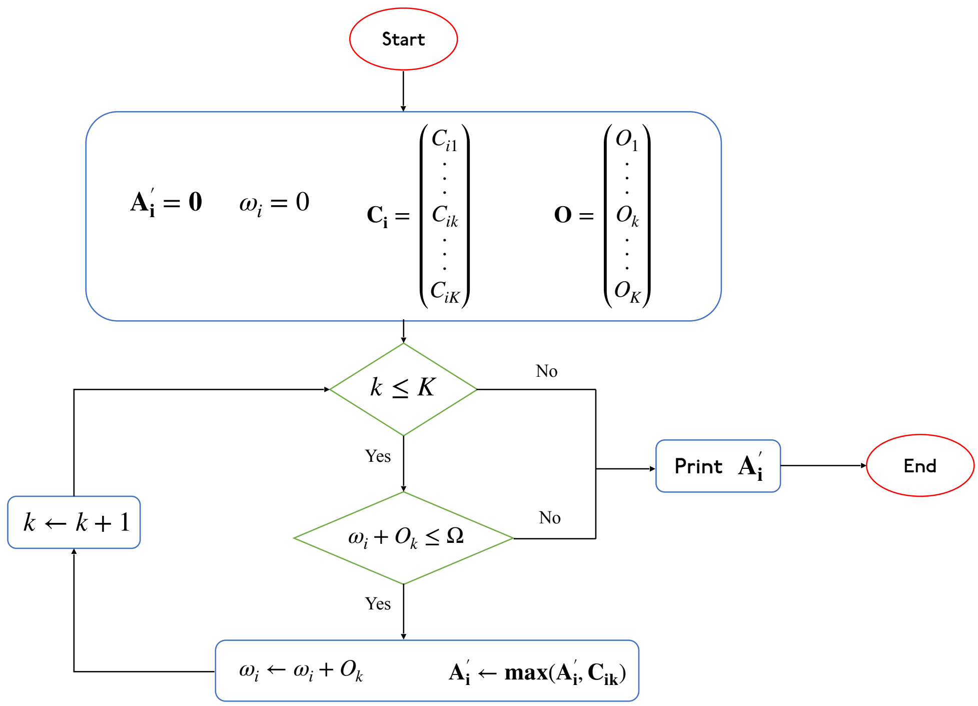


Figure 3.2: Flow Chart for Calculating Dual Access. Source: (Cui and Levinson Cui and Levinson). Note: C_i sorted in ascending order; O_j has the same order as $\mathbf{C_i}$

- ω_i is a temporary variable for storing the cumulative destinations (e.g. jobs) reached at the k^{th} iteration.

The algorithm iterates by zones from 1 to k, thereby gradually increasing travel cost, adding reachable jobs from the most easily reachable locations (lowest travel cost), to more distant locations, until the threshold number of jobs (Ω) is reached. The travel cost at that iteration becomes the output for the dual access of location i. In Appendix E we provide an R script for calculating dual access.

The primal and dual access measures provide two different perspectives on access. If the measurement is sufficiently precise, the primal access measure (A) of the number of opportunities reachable in t minutes maps directly to the dual measure telling us it takes t minutes to cover A opportunities.[41]

[41] (Breheny 1978).

Advantages.

- The dual access measure is intuitive and aligns well with the perception of the traveling public. The dual access is easily perceptible for comparing access between locations, and between cities. For primal measures, significant variation in the number of reachable opportunities can result from small changes in the travel time threshold. The difference in the number of reachable opportunities between cities can be extreme, making it difficult to meaningful compare primal access measures across cities. An access measure denominated in minutes, however, may provide a more readily perceived and readily compared scale.

- The dual access measure can be quantified intuitively as the time cost for completing certain tasks, which avoids setting a random threshold number of opportunities. For example, the time cost for completing a shopping trip, or a visit to dentist. Conceptually, this concept of time cost could be extended to online shopping, or other versions of digital access, as described in subsection 2.4.1.

DISADVANTAGES.

- Without a good reference, the setting of any threshold number of opportunities beyond '1' is often arbitrary. There is little consensus on the minimum number or range of opportunities of various types that are required to maintain full participation in society. Moreover, travel time alone may not reflect the actual need or preferences of people. For instance, one's primary shopping location may not necessarily be the one closest to home. [42]

[42] (Burns and Warren 1995).

- The calculation of dual access is less straightforward than for primal access (when the number of opportunities exceeds one).

- Time-denominated dual access measures are a field of active research. Therefore, best-practices in the use of dual measures, and the relation of dual measures to travel behavior are less established than for the opportunity-denominated primal access measures.

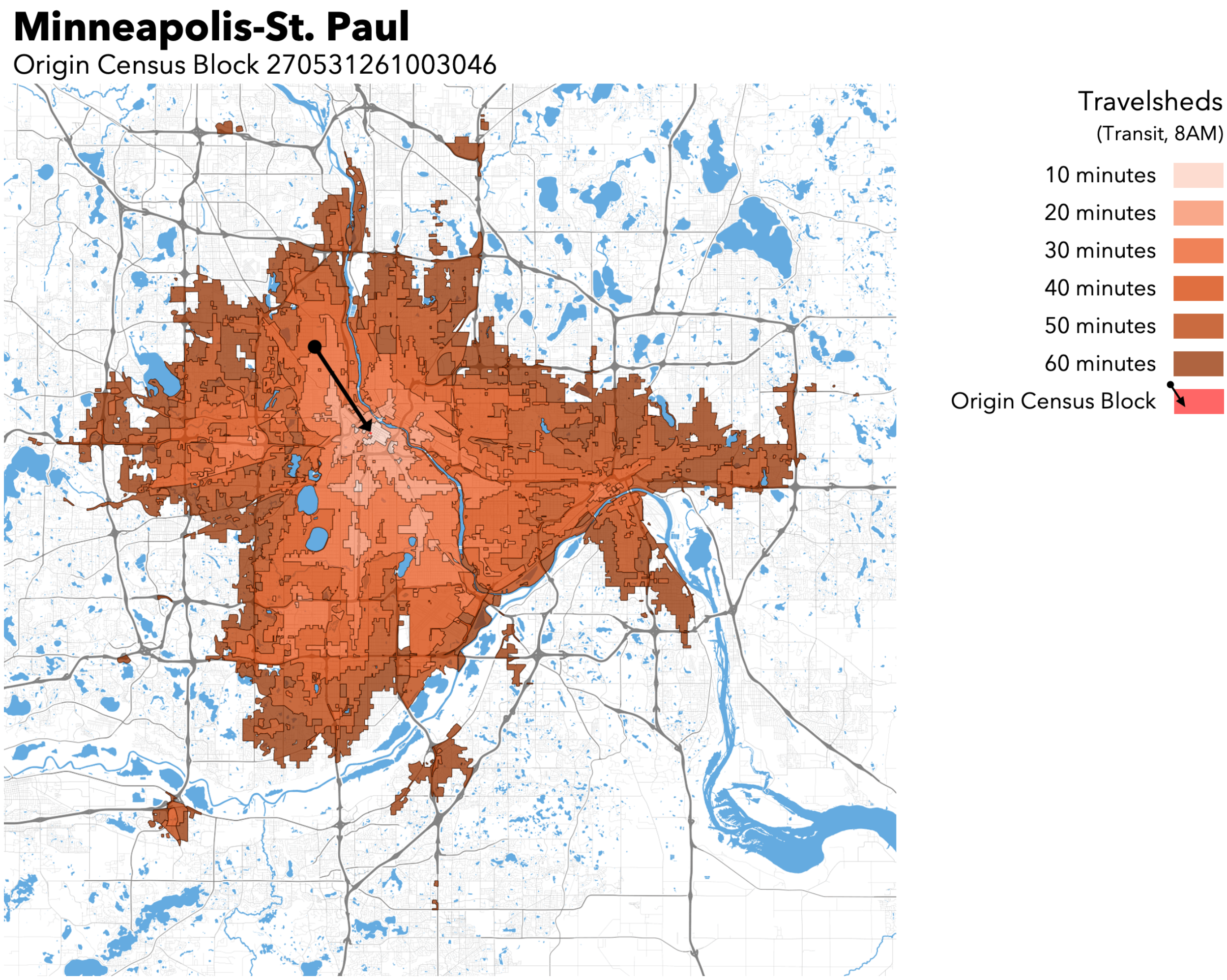


Figure 3.3: Minneapolis - Travelsheds by Transit. Source (Accessibility Observatory 2017).

4
Calculations

This chapter illustrates step-by-step procedures for calculating the access measures introduced in chapter 3:

- Identify Objectives (section 4.1)
- Stratify analysis (section 4.2)
- Determine travel costs (section 4.3)
- Determine opportunities at destinations (section 4.4)
- Accumulate opportunities reachable from origins (section 4.5)
- Assess a competition-based access Measure (section 4.6)
- Calculate a dual (time-denominated) access measure (section 4.7)
- Summarize using aggregate indicators (section 4.8)
- Visualize results (section 4.9)

4.1 *Identify Objectives*

The first question is 'What are the aims?' Identifying objectives help clarify this. Every community has its own process for establishing goals and objectives, processes beyond the scope of this manual.

Some communities have established clear access-related objectives, which the analyst then should use, along with other measures the analyst believes to be important. While the issue of standards is discussed more fully in section 2.3, in communities where objectives have been established, those are required to assess whether desired policy outcomes have been achieved.

In communities without clear access-related objectives, particularly those where access is a new concept, the analyst should measure access in as much detail as possible to establish a baseline of information for future objective-setting and evaluations.

To establish a baseline, such as the number accessible jobs, a time threshold (e.g. 30 minutes) should be adopted, and other components of the measurement process need to be documented and standardized so that before and after comparisons are internally consistent.

4.1.1 *Example: Policy Goals*

To help solidify your understanding of access calculations, this chapter uses the case of Example City to illustrate the various issues.

In Example City policymakers have set the following objectives:

- 80% of residents can access at least 50% of the region's jobs within a reasonable commute during the peak.
- 100% of residents can access a grocery store within 10 minutes in off-peak conditions.
- 90% of residents can access hospital care, adjusted for competition, in 30 minutes in off-peak conditions.

4.2 *Stratify Analysis*

The next question is 'What is being measured?' Stratifying analysis allows clearly defining what is being examined. When following these procedures, it is essential to stratify analyses to account for what question is being asked and to consider stratifying for individual capabilities and demographics. The analyst may want to stratify by:

- DESTINATION TYPE. Workplaces, groceries, schools, medical offices, parks, airports and so on are all different types of destinations, serving different activities and purposes. An access analysis must choose which destination(s) are relevant. Measurement of access to workplaces are common in the literature, both because of importance (in most developed countries almost half the population works, and for workers, it is the out-of-home location where the most time is spent and the longest travel is engaged with) and convenience (the location of jobs and workers is often well established with Census or other administrative data). However other activities are also important to consider.

- TIME-OF-DAY. Both travel times and number of opportunities vary by time-of-day. Jobs available from 9:00 am - 5:00 pm might not be available from 9:00 pm to 5:00 am. Stores have specific open hours. Thus access varies by time-of-day. This means, in principle, a specific time-of-day for the analysis must also be selected. While data for the variation in travel time by time-of-day is now generally available for travel by automobile and public transit, and it is assumed invariant for walking and bicycling, data for variation in opportunities by time-of-day is often unavailable.[1]

  For access to jobs, morning peak hour or peak period is widely used as a measure as most jobs are available in the morning. However a significant percent of workers begin work in the afternoon, evening, overnight, or in the early morning. For access to other destinations, the appropriate time-of-day may vary.

- MODE AND AVAILABILITY. For which mode or modes is the analysis being conducted? The most common modes: walk, bike, public transport, and driving each require distinct analysis. Not all modes are available to every traveler.

[1] For a study using open hours of opportunities, see Delafontaine et al. (2011).

Most access measures only consider a single mode at a time. As a result, the analysis must delineate explicitly each mode to be taken into consideration, including auto, public transit, biking, walking, and other micromobility modes. Walk-to-transit and drive-to-transit should be considered as separate modes. For equity analyses, non-auto modes should be considered, since many low income and disadvantaged households are more likely to rely upon transit, walking, biking, and micromobility options. In policy environments where multiple modes are encouraged, analysis of all viable modes should be included. Including the full range of modes, however, can present other analytical difficulties, as the zonal structure that is appropriate for auto travel is generally too gross to represent public transport, pedestrian, and bicycling travel choices. Full data on travel time or cost must be available for each mode that is analyzed.

Availability of transport infrastructure and transit services shapes overall access levels. If capacity is limited on surface transport, or if frequency is low for transit services, the ease of travel decreases and duration increases. The availability of a car for an individual, or the availability of walkable transit service, or a mobility impaired service makes a difference in the potential versus realized access available to an individual, group, or neighborhood. If one cannot take advantage of the transport system, the economic, health, and quality of life benefits of access to opportunities cannot be realized. Part of the access equation is the political and economic realities of the region. For instance, many smaller and more rural communities typically do not have the demand to justify scheduled public transport options. They also have fewer economic opportunities, meaning travel is necessary to meet the needs of residents. Longer duration trips are required to reach an equivalent set of destinations to those of suburban/urban communities. With limited resources, the availability of transport options and economic opportunity in small communities impacts the access level of the region.[2]

[2] The related issue of affordability is discussed in section 2.9.

- DEMOGRAPHICS.

  Access analyses can be disaggregated into different transport disadvantaged groups, such as people with disabilities, people with low incomes, youths, elders, etc. The incremental costs they bear for basic access relative to drivers can be considered an indicator of transport options.[3]

[3] As pandemics teach, there is even value to access to the absence of people, as sometimes people want to be isolated. Thus, planners should not assume that increasing access to any particular opportunity is always an appropriate end.

For instance, if the travel opportunities of seniors are of interest, access measures are easily customized to take into account where this population is most prominent.

The downside of disaggregation is that as the number of analyses multiplies, it becomes easier to lose the big-picture trends due to the excessive supply of results. The correct balance of disaggregation and aggregation again depends highly upon the intended audience and goals of the access measurement effort. The most common analyses examine the entire population, or workers, but many analyses, especially those concerned with distributional or equity effects, should stratify the population into subgroups.

- CAPABILITY. Individual capabilities are a component of access. Factors such as age, fitness level, and disability along with the presence of children, luggage, groceries, or other items can all impact the ability to reach jobs and services using the transport network. Whether reducing trip-making, or limiting the duration of travel, the lack of step-free access and other features of universal design may limit access for those living and working with mobility challenges.[4] The ability of an individual or group to access transport – physically and monetarily – are determining factors in the realized access of a region. A breakdown showing how access is limited for users who can use only the step-free network can highlight important areas for improvement. Figure 6.1 evidences the extent to which people with disabilities can (or cannot) travel through the London Underground and Trains network.

[4] The economic impact of improving transport and travel conditions for these groups of people and travel conditions has implications extending from reduced social care costs to increased participation in activities (International Transport Forum 2019b).

4.2.1 Guidelines

CRITICAL.

- Define the activity (destination) types being considered.
- Define the time-of-day being examined. Is this a single point of time or a range of times? For work trips, at least use the morning peak hour travel time.
- Define the modes being examined.
- Define the population being examined.

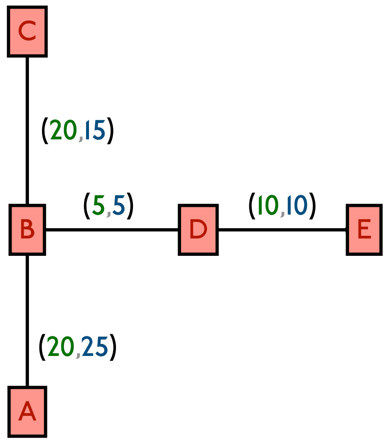


Figure 4.1: Example: Network. Peak travel time in Green, off-peak travel time in Blue. *Note: Travel times are assumed identical in each direction.*

Origin	Destination A	B	C	D	E
A	0	25	45	30	40
B	25	0	20	5	15
C	45	20	0	25	35
D	30	5	25	0	10
E	40	15	35	10	0

Table 4.1: Example: Peak Travel Time Matrix.

Origin	Destination A	B	C	D	E
A	0	20	35	25	35
B	20	0	15	5	15
C	35	15	0	20	30
D	25	5	20	0	10
E	35	15	30	10	0

Table 4.2: Example: Off-Peak Travel Time Matrix.

4.3 *Determine Travel Costs*

The next step in calculating access is determining representative travel costs between all potential places of interest (C_{ij} in Equation 3.1 for origins i and destinations j). Typical data sources for travel costs are discussed in section 6.3.

Access measures in urban transport applications often use centroids of areal units (e.g. transport analysis zones (TAZs), census blocks, etc.), linked to the transport network with centroid connectors, to represent these places. Typical measures use travel times, outward from a given origin centroid to all other centroids via the network, as the representation of travel cost. Common network analysis procedures (e.g. shortest-path algorithms) make it relatively straightforward to compute such measures.

Alternative access measures may incorporate disaggregate point-based representations of locations (e.g. individual building or facility locations, rather than the number of facilities within an areal unit), costs for trips in the reverse direction (inbound costs from all origins to a specified destination), or other components of travel cost.

Advanced access measures incorporate all relevant costs into full generalized costs or reflect multiple simultaneous constraints. [5] Such costs might include fares or number of transfers for travel by public transport, exposure to pollution and collision risk for travel by auto, etc.

[5] (Conway and Stewart 2019, Cui and Levinson 2018b, El-Geneidy et al. 2016).

When computing or reporting access measures, it is important to specify clearly the parameters affecting travel cost. In particular, time of day (e.g. peak vs. off-peak) and modes of travel affect speed and should be specified clearly. Other relevant routing considerations may disallow certain paths through the network. For example, travel by automobile might be allowed only in non-managed lanes (e.g. without toll or high-occupancy restrictions), travel by bicycle might be allowed only on low-traffic-stress links, or travel by public transport might be allowed only using only stations with step-free access and level boarding.

As described in section 6.3, travel costs are often available as 'skim' matrix outputs from strategic planning models. If such results are not available, other tools may be helpful in determining batches of travel times from specific origins; section D.2 covers such tools.

We can use the data from the travel time matrix to compute an access matrix (Table 4.4), a binary indicator of whether two zones are accessible to each other. Any cell with a time under the threshold (e.g. 30 minutes) is marked with a 1, others are marked 0.

4.3.1 *Guidelines*

Critical.

- Determine appropriately representative travel costs (e.g. total travel time) between a given location and all other locations.
- Explain what is included in the travel cost when reporting access indicators. Usually, such clarification requires stating the time components included, mode, and time-of-day (e.g. travel time by automobile, 8:00 am; or total travel time by walking plus public transport, off-peak). The source of the data should also be reported to maximize transparency and reproducibility.

Recommended.

- Calculate travel times for multiple modes, times-of-day, and universal-access requirements (such as wheelchair ramps), appropriate to the the investment, development, or policy being evaluated. Some analyses use monetary or social costs as well.

Optional.

- Weight components of travel time differently (e.g. walking vs. in-vehicle), and incorporate other components of overall cost.

To	Peak	Off-peak
A	0	0
B	25	20
C	45	35
D	30	25
E	40	35

Table 4.3: Example: Isochrone Analysis of Travel Time from Location A.

Origin	A	B	C	E	E
A	1	1	0	1	0
B	1	1	1	1	1
C	0	1	1	1	0
D	1	1	1	1	1
E	0	1	0	1	1

Table 4.4: Example: Peak Period Access Matrix, at 30-minute Threshold, 1 indicates zones are accessible, 0 indicates inaccessible within 30 minutes.

4.3.2 *Example: Network*

Example City in Figure 4.1 has one mode of transport available, and can be represented by a simple network with 5 nodes and 4 links. The travel times to traverse each link during peak (green) and off-peak (blue) periods are shown.

Using Example City, the time to reach each other locations from A is shown in Table 4.3. This type of calculation for a single origin is sometimes called *isochrone analysis*, because it facilitates identifying all destinations within a fixed travel time threshold (isochrone). Note that the values for location A are also available as Row A in the travel-time skim matrices for peak (Table 4.1) and off-peak (Table 4.2) conditions.

4.4 Determine Opportunities at Destinations

The next step is quantifying the opportunities located at each possible destination point or zone. This process is straightforward using a point-based representation (e.g. specific facility locations, or centroids). Alternatively, opportunities in a given zone can be assumed to be uniformly distributed throughout the zone.

Typically, a basic count will be used (e.g. total number of jobs associated with each destination). The size quality of amenities can also be assessed (e.g. area of green space). In assessing food access and the presence of food deserts, for example, the average cost of produce can be indexed and used as a weighting factor. Analyses can also be stratified by specific classes of opportunity (e.g. low-, medium-, and high-earnings jobs). Typical data sources for opportunities are discussed in section 6.2.

4.4.1 Guidelines

Place	Pop.	Jobs	Stores	Beds
A	550	50	1	600
B	200	200	2	0
C	400	100	0	0
D	50	600	0	800
E	200	50	0	0

Table 4.5: Example: Demographics and Land Use by Location

CRITICAL.

- Count opportunities at each possible destination point. If the source data are unavailable at the desired resolution, aggregation or sampling is required.

RECOMMENDED.

- Include multiple types of opportunities, and/or weighting access to destinations by measurable qualities of the opportunities at destinations.

OPTIONAL.

- Stratify by destination type (e.g. jobs by earnings, jobs by industry, etc.) to report how access to different classes of opportunities varies.

4.4.2 Example: Demographics

For Example City, assume relevant demographics (Population) and opportunities (Jobs, Hospital Beds, Grocery Stores) have been tallied for each node, shown in Table 4.5.

4.5 Accumulate Opportunities Reachable from Origins

In order to measure access to opportunities from a specific origin, each destination needs to be associated with a travel time from that origin. Then, the number of opportunities reachable from the origin can be tallied, using either a unweighted or weighted cumulative opportunities approach (see chapter 3).

In the unweighted cumulative opportunities approach, with a single travel-time cutoff, each destination is classified as either reachable or unreachable. In the weighted cumulative opportunities approach, the number of opportunities is weighted by the chosen impedance function.[6]

[6] If zones are represented as areal units, rather than centroids, the number of opportunities can be determined using the areal proportion reachable within the cutoff in the basic approach, and using some sampling method in the cumulative opportunities approach.

After opportunities at a destination are counted and differentially weighted as needed, that singular aggregate value is assigned to that destination for the travel time budget imposed. As this process is performed for all possible combinations of origins, destinations, and travel time thresholds within the evaluation framework, an access landscape is produced.

4.5.1 Guidelines

Recommended.

- Test and report indicators with different cutoffs (e.g. 15, 30, 45, and 60 minutes) when using the basic cumulative opportunities approach.

Optional.

- Consider a weighted cumulative opportunities approach.
- Consider adjusting for competition.

Place	Jobs (30 min.)	Jobs (weighted)	Grocery stores	Hospital capacity
A	850	504	1	1.32
B	1000	947	2	1.32
C	900	692	0	0.57
D	1000	935	2	1.32
E	850	844	0	0.57

Table 4.6: Example: Access Results

4.5.2 *Example: Access to Jobs*

Recall the policy goal:

- 80% of residents can access at least 50% of the region's jobs within a reasonable commute during the peak

An analyst might decide "within a reasonable commute" could be defined for the peak period using a 30-minute cutoff for a basic cumulative opportunities measure.

For origin A, destinations B and D are within a 30-minute commute during the peak (see Table 4.3). The jobs at those destinations (200 and 600, respectively, see Table 4.5), as well as the jobs at A, would be considered accessible according to this formulation, yielding a 40-minute job access of 850. Similar calculations using the other nodes as origins are shown in the table.

The results of the calculations described above are summarized in Table 4.6.

Example City has 1000 jobs total. For the two job access measures chosen, 100% of residents have access to at least 50% of the city's jobs; the policymakers' job access objective is achieved. Note that with the basic cumulative-opportunities measure, E is tied for the lowest job access; with the weighted measure, it has the third lowest. These results illustrate how basic cumulative-opportunity measures are sensitive to the cutoff chosen. While A and C are more than 30 minutes away from E, the jobs there are likely to benefit residents at E to some extent, so they should not be disregarded entirely.

4.5.3 *Example: Access to Jobs using Logistic Impedance Function*

Applying an impedance function, in this case, the logistic impedance function from Table 3.1 with $\kappa = 0.15$ and $C_{infl} = 30$, as a proportion of a given opportunity co-located with the origin, an opportunity 25 minutes from the origin would be equivalent to 0.679, an opportunity 30 minutes from the origin would be equivalent to 0.500, an opportunity 40 minutes from the origin would be equivalent to 0.182, and an opportunity 45 minutes from the origin would be equivalent to 0.095.

Using these weights and the values in Table 4.3 and Table 4.5, for origin A, the 200 jobs at B would be equivalent to $0.679 \cdot 200 = 136$, the 100 jobs at C would be equivalent to $0.095 \cdot 100 = 9.5$, the 600 jobs at D would be equivalent to $0.500 \cdot 600 = 300$, and the 50 jobs at E would be equivalent to $0.182 \cdot 50 = 9.1$. Including the jobs at A, the weighted jobs reachable from A total 504. Similar calculations are performed using the other nodes as origins, shown in Table 4.6.

4.5.4 *Example: Access to Grocery Stores*

For grocery stores, the policy goal was:

- 100% of residents can access a grocery store within 10 minutes in off-peak conditions

In Example City, only nodes A and B have grocery stores. In off-peak conditions (see Table 4.2), from origin C, no other nodes are within 10 minutes, so residents at C lack access to a grocery store. From origin D, the grocery stores at B are reachable within 10 minutes. From origin E, no grocery stores are within 10 minutes.

The results of the calculations described above are summarized in Table 4.6.

Residents at C and E lack grocery store access according to the chosen formulation; policymakers' grocery store access objective is not achieved. This inadequacy could be rectified either by building grocery stores at these locations, or by reducing off-peak travel times from C to B and from E to D by 5 minutes.

4.5.5 *Example: Access to Hospital Capacity*

The policy goal for hospital care was given as:

- 90% of residents can access hospital care, adjusted for competition, in 30 minutes in off-peak conditions

Access to hospital beds are not useful if those beds are occupied. So here, a competition-adjusted access measure is constructed, following the discussion and equations in subsection 3.1.3.

Calculating a competition-adjusted access measure is a two-step process.

- First, the number of opportunities at each node are divided by the number of people who can access those opportunities. For example, using a 30-minute cutoff, the 600 hospital beds at A are shared between residents at A (550), B (200) and D (50); the adjusted capacity at A is accordingly $600/(550 + 200 + 50) = 0.75$. Similarly, the adjusted capacity at D is 0.57.
- Next, these adjusted opportunities are used in access calculations for origins as above. Within 30 minutes, for example, the residents at A and B have access to $0.75 + 0.57 = 1.32$ units of competition-adjusted hospital capacity. The residents at C can access D but not A, so they have access to 0.57.

The results of the calculations described above are summarized in Table 4.6.

Residents at C and E also lack adequate access to hospital care, according to the chosen formulation. The combined population of these origins is 600, equivalent to 43% of the population; policymakers' healthcare access objective is not achieved. This inadequacy could be rectified by improving transportation to the hospital at A, or shifting hospital capacity from A to D.

A more complicated competition adjustment method is described in section 4.6.

4.6 *Assess Competitive Access*

The competitive access measure described in subsection 3.1.3 discounts opportunities at the destination by the level of demand reaching those opportunities. Competitive access uses the ratio between the number of opportunities inside a destination, and the number of people that can reach this destination under a time threshold, to represent the actual level of available opportunities. The same time threshold is then used to determine which destinations are reachable; the sum of ratios across all reachable destinations becomes the competitive access measure.[7] Section 4.6.2 and Table 4.7 present an example of how to calculate competitive access to jobs for a particular origin using this method.[8]

[7] This method is referred to as the 'Two-step Floating Catchment Area' in GIS applications.

[8] There are many other methods to discount the number of opportunities within destinations (Cervigni et al. 2008, Joseph and Bantock 1982, Kawabata and Shen 2007, Luo and Wang 2003, Mao and Nekorchuk 2013, Neutens 2015, Van Wee et al. 2001).

More complicated methods may apply impedance functions, or consider the competition from different modes of transport. The choice on how to discount opportunities generally depends on the goal of the access measure, and the data available.

4.6.1 *Guidelines*

For activities that are subject to competition (e.g. jobs which can be only held by one person), a competitive access measure can be used. These measures may be unweighted or weighted cumulative opportunities measures.

CRITICAL.

- Discount the number of available opportunities within each destination by demand.
- Sum the discounted opportunities within each reachable destinations.

RECOMMENDED.

- Account for competition by different modes of transport.
- Consider the temporal variation of both the demand for, and the supply of, opportunities.
- Stratify and match different demands with specific categories of opportunities to improve realism.
- Select the method of discounting opportunities based on the goal of access measure, and data availability.

4.6.2 *Example: Competition Measure*

Table 4.7 shows the calculation procedure to estimate the competitive access to jobs for location A, under a 30-minute time threshold. We repeat this for each location.

- Access at the Destination for Workers. To do this, we tabulate the number of workers that can reach each zone (A - E) within 30 minutes in the fifth column ($A_j^{\circlearrowleft}$). (See Equation 3.4.)

- Discount Opportunities to Competition. We then compute the ratio of local jobs to the number of incoming workers in the sixth column ($g(O_j)$). (See Equation 3.5.)

- Competitive Access. We then identify the destinations (population) reachable from each zone (A_i^g). (See Equation 3.6.) For place A within 30-minute peak travel time threshold, travelers can reach places A, B and D (which are *italicized*). The opportunities to demand ratios in these three zones are summed up (0.6345) as the competitive access to jobs for A, as shown in **bold**.

  We repeat this calculation for all the zones in the next to final column. Two of the more central places in the example, B and D, can reach all other places within 30 minutes, as shown earlier in Table 4.4, and so have the highest access. The places at the edge A, C, and E cannot reach all other places, and so have lower competitive access scores, as expected. Because the total number of people exceeds the number of jobs, the score is below 1 (each job is competed for by more than one person).

- Normalization. Of course not all people are workers, and using workers here instead (assuming a ratio of 1.4 people per worker) would normalize the table, so that totals center around 1.0. This can of course be done at an earlier stage, or with the use of workers rather than population initially.

- Summarize: Person-weighted Competitive Access. Four of the five places have a competitive access above 1.0, this is analogous to a job/worker ratio. However the place with the most residents, A, does not. We can compute a person-weighted measure for Example City, by weighting each normalized access result by the population experiencing that access. This comes out to 1.0, as shown in Blue in the final cell of Table 4.7.

Place	Pop. (D_i)	Jobs (O_j)	Access to Jobs (A_i)	Incoming Workers ($A_j^{\circlearrowleft}$)	Discounted Opportunities ($g(O_j)$)	Competitive Access (A_i^g)	Normalized ($A_i^{j/w}$)
A	550	50	850	800	*0.0625*	**0.6345**	0.889
B	200	200	1000	1400	*0.143*	0.85	1.19
C	400	100	900	650	0.153	0.725	1.015
D	50	600	1000	1400	*0.429*	0.85	1.19
E	200	50	850	800	0.0625	0.7775	1.086
Total	1400	1000					1.0

Table 4.7: Example: Competitive Access to Jobs, at 30-minute Threshold

	Origin - A	
Dest.	Peak Time (min.)	Off-Peak Time
A	0	0
B	0	0
C	20	15
D	5	5
E	15	15

(a) Example: Time to Nearest Store

	Origin - A		
Dest.	Travel Time (min.)	Jobs	Jobs Reached
A	*0*	**50**	50
B	*25*	**200**	200
C	45	100	0
D	*30*	**600**	600
E	40	50	0
Total			850

(b) Example: Dual Access to 800 Jobs

Table 4.8: Example: Dual Access.

4.7 *Calculate Dual Access*

The calculation of dual access measure requires setting a threshold number of opportunities, and a travel time matrix. We present two examples (subsection 4.7.1 and subsection 4.7.2) illustrating the computation for the simple case of time to nearest store and the more complex case of time to reach 2700 jobs.

4.7.1 *Example: Dual Access to Stores*

Consider a simple case where the access to a single grocery store is considered (threshold number of stores = 1). The question is: How many minutes does it take to get to the nearest store?
Using data from the example (Figure 4.1 and Table 4.5) , A and B already have stores, so the time to the nearest store is assumed to be 0. Note: we may wish to have an intra-zonal travel time, in which case there would be a positive value of time, but we ignore that in this example. Residents in other locations have to travel. C is nearer to B, so the time is 20 minutes in the peak, 15 minutes in the off-peak (20,15). D is also nearest B, and the times are (5,5), and the time from E to B is (15,15)
This is summarized in Table 4.8(a).

4.7.2 *Example: Dual Access to Jobs*

Table 4.8(b) shows the calculation procedure to estimate the dual access to jobs for location A. The threshold number of jobs is set at 800; the travel time is then raised incrementally from zero, until the cumulative number of jobs reached within the raised time threshold reaches, or exceeds, the target number of jobs, at 800. This target jobs number is reached at 30 minutes, reaching jobs in location A, B and D (travel times *italicized*, number of jobs noted in **bold**); due to the lumpiness of zonal boundaries, 850 jobs are reached at this threshold instead of the 800 target.

4.8 Summarize Measures

In many urban planning applications, it may be useful to calculate aggregate measures that summarize region-wide access. For example, the increase in average number of jobs reachable within 45 minutes for a region's workers could be one measure of the benefit of a transport investment. Such aggregate measures require repeating the steps described in previous sections for all origins ($i \in I$): calculating travel times from each origin to destination locations, associating opportunities to those destination locations, and discounting the potential opportunities.

$$A_{pw} = \frac{\sum_{i=1}^{I} P_i A_i}{\sum_{i=1}^{I} P_i} \quad (4.1)$$

Aggregate measures are most commonly weighted by a relevant population associated with each origin (P_i). For example, the number of jobs reachable from each origin zone can be weighted by the number of workers residing in it to calculate the number of jobs reachable by the average worker in a region, person-weighted access (A_{pw}). This is shown by Equation 4.1.

While the weighted average access may be informative, it is also important to consider the distribution of the population's access. Consider the level of access at different locations across a region, percentiles of the access distribution, or for specific groups.

Access measures can be disaggregated by population segment and analysts should make use of this flexibility to target their analyses appropriately.

For instance, if the travel opportunities of seniors are of interest, access measures are easily customized to take into account where this population is most prominent. Likewise, specific destinations, such as parks and schools, can be identified as of policy interest.[9]

[9] Calculating the impact of a transport investment in terms of average access for members of different groups (k) can highlight potential disparate impacts. The number of people in each population group is used as a weight in aggregating access (Equation 4.2).

$$A_{pw,k} = \frac{\sum_{i=1}^{I} P_{i,k} A_i}{\sum_{i=1}^{I} P_{i,k}} \quad (4.2)$$

4.8.1 *Guidelines*

CRITICAL.

- Compute person-weighted access to summarize results for a particular case or scenario.

RECOMMENDED.

- Weight measures by specific population groups at each origin, such as people residing in communities of concern or environmental justice populations.
- Use caution when comparing aggregate access measures between metropolitan regions, as differing travel patterns or jurisdictional boundaries may affect results.

CAUTION: PERCENTAGES VS. ABSOLUTES.
The use of relative vs. absolute access measures sometimes arises. While relative measures (or percentages) are useful for comparing within a particular context (before and after some change, for instance), they are dangerous for comparing between contexts. For instance, suppose you are told that residents in City A can reach 100% of metropolitan jobs within 90 minutes by transit, but residents in City B can only reach 50% of metropolitan jobs, does City A have better access by transit? It depends on how many jobs are available, if City A is small and City B more than twice as large, the answer is maybe not, as the large city resident can reach many more total jobs by transit, even as there are many more jobs available.

4.8.2 *Example: Person-weighted Access to Jobs*

Person-weighted access weights the access from each origin by the population of each origin to estimate an average for the entire region, as shown in Equation 4.1. Given the accessibilities we calculated, and the population, shown in Table 4.9, the calculations for this example are given below:

$$A_{pw} = \frac{(550 \cdot 850) + (100 \cdot 1000) + (400 \cdot 900) + (50 \cdot 1000) + (200 \cdot 850)}{550 + 200 + 400 + 50 + 200} = 891 \qquad (4.3)$$

4.9 *Visualize Results*

Mapping is an effective way to gain an understanding of the spatial structure of access throughout a geographic area, which depends on both land-use patterns and the structure of the transport network. The typical methodology of visualizing access involves creating colorized heatmaps[10] which depict the aggregate access at each origin of interest, and coloring the origin geographies accordingly.

[10] Also referred to as *choropleth* maps.

Additional illustrative maps visualizing access are included in chapter 2 (e.g. Figure 2.1). Mapping the change over time and due to projects in access offers insights into the underlying forces which shape access (e.g. Figure 2.3).

In order to facilitate understanding of the access landscape and how aggregate access is calculated, a few additional types of visualizations can be created. First, the distribution of opportunities themselves can be mapped, to show where e.g. job centers or health care facilities are located. Second, the reachable area for a given trip from a specific origin can be mapped – this is what is called a 'travelshed,' and is integral to the calculation of access; the associated 'isochrone' is the outer boundary of the travelshed. A travelshed shows the collection of reachable destinations, for a given set of parameters (origin, mode, departure time, and travel time threshold); the opportunities at this subset of destinations are what is aggregated to a single figure when assigning an access metric to that set of parameters. Figure 3.3 shows such a travelshed from a US Census block, for 30 minutes of travel time on transit in the city of Minneapolis, Minnesota.

Place	Pop.	Jobs (30 min.)
A	550	850
B	200	1000
C	400	900
D	50	1000
E	200	850
A_{pw}		891

Table 4.9: Example: Person-weighted Access (A_{pw})

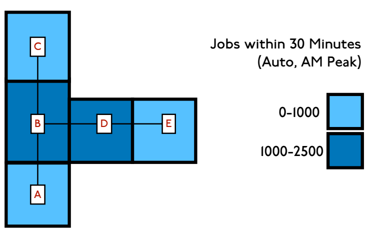


Figure 4.2: Example: Access Visualized as a Heatmap.

4.9.1 *Guidelines*

RECOMMENDED.

- Use travelshed (isochrone) maps to illustrate the access afforded by different scenarios for illustrative or representative origins.
- Use access heatmaps to illustrate how access changes for all points in a region. An exemplary color scheme is shown in Figure 4.3.

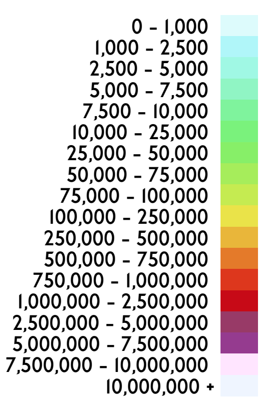


Figure 4.3: Exemplary Color Scheme

5
Biases

Transport and land use data can be organized in various ways, raising different types of methodological issues in access analysis. This section equips you with a basic understanding of several known biases that arise in spatial statistical analysis that are relevant to access computations, and discusses considerations and trade-offs between common methods of computing access. While there are a great diversity of biases that occur in spatial statistics, only a few have acute impacts on access analysis. These biases result from the various ways we represent networks and opportunities. This section discusses considerations and trade-offs between common methods of computing access, and provides guidelines for avoiding or mitigating potential biases.

We organize them into boundary, aggregation, and starting problems with spatial and temporal instances as shown in Table 5.1.

Issue	Spatial	Temporal
Boundary	Edge Effects (section 5.1)	
Aggregation	Modifiable Areal Unit Problem (section 5.2)	Modifiable Temporal Unit Problem (section 5.3)
Starting	Starting Point Effects (section 5.4)	Starting Time Effects (section 5.5)

Table 5.1: Summary of Methodological Issues

5.1 Edge Effects

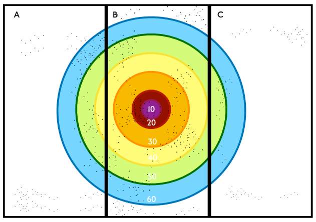


Figure 5.1: Edge Effects Occur when the Study Area does not Include all Relevant Destinations.

Boundary or edge effects are a bias in spatial analysis that results from the imposition of explicit, discrete boundaries on unbounded spatial phenomena that are distributed in continuous space. It may occur when not representing destinations and network outside the boundary of a study area. The analysis could be cut off at network locations along the edges, or destinations outside the study area could not be counted. As a result, the access measured at the edges of the study area would be lower than it should be. This is a common issue in delimiting the study area.

An example is provided in Figure 5.1. The diagram shows three jurisdictions (A, B, C) and 10- to 60-minute travel sheds for someone located in the center of jurisdiction B, with opportunities denoted by dots. In the diagram, someone located in the central ring (the 10-minute travelshed) can reach some areas in the 50 and 60-minute travelsheds that are outside jurisdiction B (in A or C). So an analysis of that location which confined itself to the home jurisdiction would miss many destinations.

Boundary effects for access analysis can result from not having enough information on transport networks or relevant destinations for areas outside the study area. The analysis can be cut off at the edge of a network, or destinations outside the study area could not be counted. When measuring 10-minute walk access from an urban destination, a smaller study area can be chosen than when measuring 60-minute access by automobile to jobs from homes at the edge of a metropolitan area.

5.1.1 Guidelines

CRITICAL.

- Ensure sufficient buffer areas around the study area. In general, the travel network for a cumulative opportunities measure with a t-minute travel time threshold should exceed the area that is expected to be covered within t minutes from any part of the study area in question by the given modes.

RECOMMENDED.

- Use study areas defined based on functional urban areas, regardless of administrative boundaries when analyzing metropolitan areas.

5.2 *Modifiable Areal Unit Problem (MAUP)*

The *modifiable areal unit problem* (*MAUP*) refers to a class of biases related to aggregated spatial data that observes how results can vary when two identical analyses are applied using different spatial scales or zoning schemes. This problem presents itself in spatial analysis results from two main effects:

- Scale Effect. This refers to how the same spatial data when aggregated using differently scaled geographies will yield different results. For example, aggregating spatial data to the county level will yield very different results and patterns from the census block group level. Both aggregations might be mathematically correct, but the aggregate and disaggregate analyses will yield answers to different questions.

- Zone Effect. This refers to how the same spatial data when aggregated using similarly scaled geographies but different zone shapes can yield very different results. For example, aggregating with square grids will yield different results than using a hexagonal grid. A classic example of the zoning effect is gerrymandering, as illustrated in Figure 5.2.

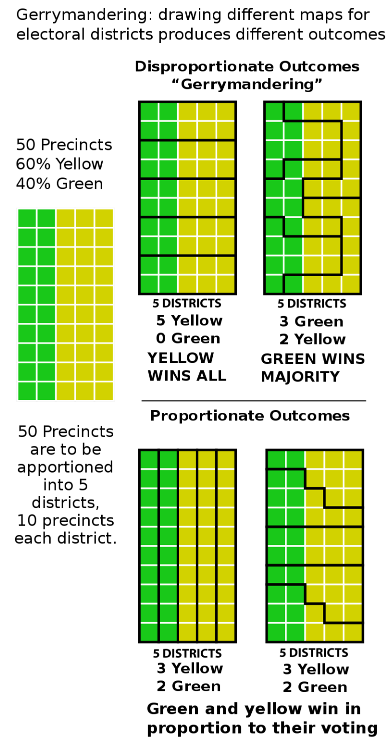


Figure 5.2: Modifiable Areal Unit Problem is Illustrated by Gerrymandering. Source: (Wikimedia Commons 2018).

5.2.1 *Guidelines*

Recommended.

The MAUP generates issues that can be minimized by ensuring that both the datasets that represent origins and destinations are:

- *Compact geographies* whose boundaries have close to the same distance from the center of the shape regardless of where along the boundary the measurement is taken.

- *Disaggregate geographies* with small zone sizes to reduce sampling bias from discrete gaps between destinations or origins.

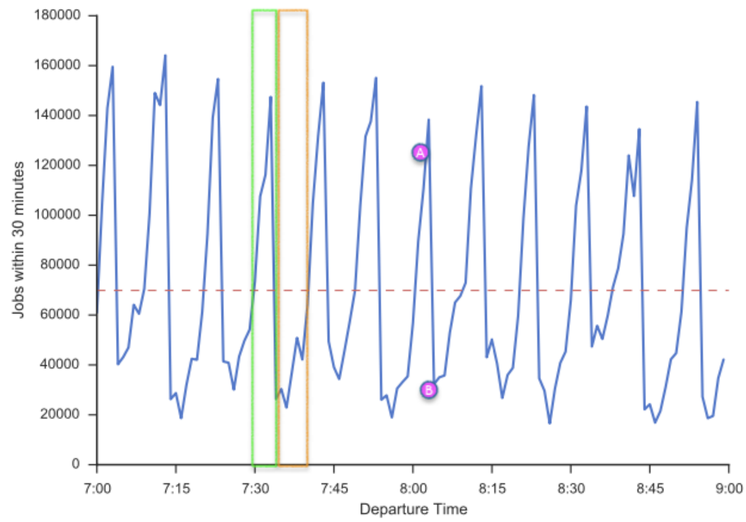


Figure 5.3: Transit Access and the Modifiable Temporal Unit Problem. Source: Adapted from (Murphy and Owen 2019b).

5.3 *Modifiable Temporal Unit Problem (MTUP)*

The *modifiable temporal unit problem* (*MTUP*) is the temporal analog of MAUP, and it refers to how the results of a given analysis can vary depending on how the data is organized using different temporal schemes. This problem results from two effects, and is related to the starting time effects question discussed below (section 5.5):

- AGGREGATION EFFECT. Aggregating data points in a temporal window using different window and sample sizes will yield different results. For example, when calculating the average accessibility of multiple departure times, the results can vary depending on the number of departures times sampled and on the period interval, say within a 30-minute or a 3-hour window. This is shown in Figure 5.3, where the period denoted by the green rectangle has much higher average accessibility than the orange-denoted period adjacent.

- BOUNDARY EFFECT. Considering different temporal lengths of the same phenomena can yield different results. For example, calculating cumulative accessibility metrics requires the selection of a maximum temporal duration of the trip, and using different travel-time thresholds can lead to very different results.

The MTUP has been largely overlooked and it is common to most accessibility studies because they generally assume a single departure time or window (often during peak-time) and a single travel-time threshold. Nonetheless, multiple studies have shown how MTUP effects can bias accessibility estimates[1] and influence the impact and equity assessment of transportation projects.[2]

[1] (Farber et al. 2014, Neutens et al. 2012, Stępniak et al. 2019).

[2] (Pereira 2019).

5.3.1 *Guidelines*

There is no single approach to overcome biases generated by MTUP, and the selection of an appropriate temporal scheme depends on the aim and context of each particular study. Nonetheless, one can minimize MTUP biases by:

RECOMMENDED.

- Analyze accessibility levels over the course of the day to account for variations in service levels during peak and off-peak times and differences in opportunities by time-of-day.
- Sample multiple departure times while considering the trade-offs between computational time and results reliability for each combination of sampling strategy and sample size.[3]
- Conduct sensitivity analysis with multiple time thresholds when using cumulative opportunities metrics. This can provide more robust results, ensuring the conclusions of access analysis in a project are not simply artifacts resulting from *ad hoc* methodological choices.

[3] For a detailed investigation of these trade-offs, see the work of (Stępniak et al. 2019) and (Murphy and Owen 2019b).

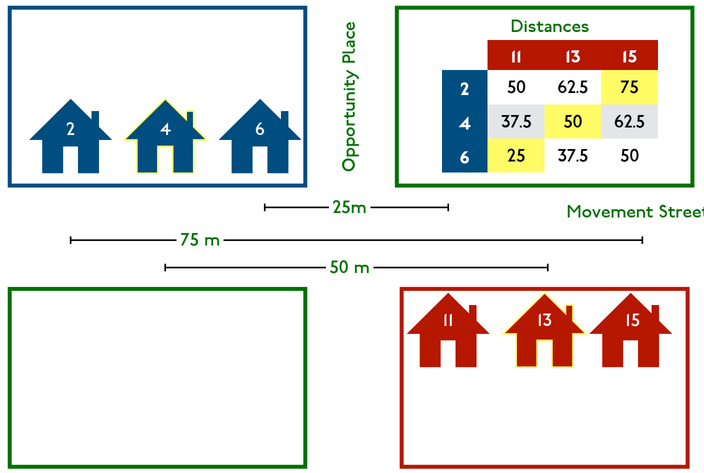


Figure 5.4: Starting Point Effect. The median travel distance from the blue to the red block is 50 m. The travel distance from 2 Movement Street to 15 Movement Street is 75 m, and from 6 to 11 is 25 m. Residents with different starting points will experience the distances differently.

5.4 *Starting Point Effects*

Starting point effects are a type of spatial sampling bias in network analysis that relates to how small changes in the starting location can create non-linear changes in cumulative travel times or other traversal statistics, as illustrated in Figure 5.4. The returns to increasing spatial resolution diminish as points become less aggregated.[4] A common example of this is how two houses that are a few blocks apart can have different travel times to the nearest store as a result of one being located on less connected part of a street network such as a cul-de-sac.[5]

[4] (Cui et al. 2019).

[5] These issues are related to the modeling issues of intra-zonal travel time and terminal time.

Minimizing issues starting point effects requires finding representative start or end points for network analysis, or sampling many different start or end points.

5.4.1 *Guidelines*

RECOMMENDED.

- Use disaggregated and compact geographies for both destinations and origins.

However, when disaggregated and compact geographies cannot be used, the creation of representative center points or the use of multiple sampling points are approaches to mitigate this.

Alternative.

- Sample access to destinations using multiple sampling points within the study zone and take a measure of centrality, such as the median, to determine the typical access value provided.
- Develop representative centers for larger zones. This can be done by using smaller geographies with measures such as population at the census block level, and computing the population weighted mean center of those smaller geographies relative to the study zone. This can be used to create starting points that are more representative of where the population is actually located.

5.5 Starting Time Effects

Starting time effects are a type of temporal sampling bias analogous to the spatial starting point effects. The counterpart example for start times is when a chosen leave time for a trip is two-minutes after a bus that comes around every hour departs. If the travel budget is 45 minutes, it could be spent entirely waiting for the next bus.

Accessibility estimates from a given location can vary depending on the departure time. The selection of the trip departure time, say at 8:00 am or 3:00 pm for example, influences accessibility results because of the variation in service levels across the day and day of the week. This is shown in Figure 5.3, where departing at time *A* produces much higher accessibility than at time *B*.

Starting time effects depend on *when* an access analysis is assumed to occur, and they are manifestations of the segmentation and aggregation effects of the modifiable temporal unit problem (MTUP) discussed above (section 5.3). This problem occurs when dealing with highly temporal network datasets that are intrinsic to automobile and transit travel. Generally this is mitigated similarly to starting points effects in that you can either use multiple trip start times or determine representative conditions. For instance, by using minute-by-minute averaged transit access between 07:30 to 08:30, which is computationally intensive[6] or a representative start time at 08:00, which will result in biases that may be acceptable depending on the analysis if properly considered and controlled for.

[6] (Murphy and Owen 2019b).

5.5.1 Guidelines

RECOMMENDED.

- Conduct analysis across multiple time points and find the most typical conditions.
- Develop average network conditions across the time period to base the analysis on. For example, calculating transit accessibility over the morning peak hour using minute-by-minute departure times from each origin will result in 60 accessibility values for each origin. These can be averaged to give the average accessibility for the region in the morning peak accounting hour for frequency of service.

6
Data

To describe the attributes of the people, places, and movement in sufficient detail to allow meaningful measurement of access, the data assembly process typically involves by far the greatest effort of any part of the process to measure access. Access tools require geospatial data (or geographic information) to be able to function. The data links information to geographic coordinates or a vector geometry. No matter the ambition, each tool requires accurate, reliable, and sometimes ample geospatial data to meet any the objectives the user intends to achieve. As such, the quantity and quality of available geospatial data can serve as a barrier to successful implementation of an access tool and the access policy to which it is related. The analyst's first priority is to determine whether the right mix of data is available or can be made available to execute their objectives.

We classify data for access into five main clusters:

- People (section 6.1),
- Places (section 6.2),
- Movement (section 6.3),
- Time (section 6.4), and
- Cost (section 6.5).[1]

This chapter describes those categories in more detail, and gives special consideration to open access data used in existing access tools.[2]

[1] (Geurs and Van Wee 2004).

[2] This chapter mentions several open source and proprietary data sources, but this does not comprise an endorsement of any particular database or vendor.

6.1 People

While location-based access tools do not require knowing who receives the access, many analyses of that data do. People thus show up twice here, both as an *object*, the opportunities to be reached, and as a *subject*, the person who is doing the reaching.

Several types of variables are typically considered to characterize people:

- DEMOGRAPHIC VARIABLES – Age, gender, ethnicity, caste, income, educational level, household situation, health status, etc.,
- ECONOMIC VARIABLES – Workplace, and type of job, income, etc.,
- CAPABILITY, SKILLS, AND TRAINING – Including mobility options, such as car ownership, as well as disabilities,
- PERSPECTIVES AND ATTITUDES – Perceived value of time, willingness to pay given services, etc.

The first two classes of spatial dataset are commonly derived from local, regional, or national databases, and are usually aggregated at a certain geographical level (e.g. postal code, neighborhood). The principal source of those data are the National Census. The spatial data representing census geographical units are also freely available from national census services, or from GIS departments or developers.

- The US Census publishes reams of demographic spatial data at the state, city, and even zip code level.[3]
- The WorldPop project that brings population at a resolution of 100 meters for different years.[4]
- The European Commission and its Global Human Settlement (GHS) framework combines fine-scale satellite imagery, census data, and volunteered geographic information. This project brings population estimates at resolutions of 250 meters and 1km for different years.
- Eurostat and EFGS have also produced population-grid datasets in 2006 and 2011 for member countries of the European Union. They use a resolution of 1 km and data from population and housing census.

[3] The data set is very good for creating access visualizations and can be accessed on the Census website.

[4] This project, which involves a number of collaborators from the University of Southampton, the University of Oxford, the World Bank and the Flowminder Foundation, includes population characteristics like age and sex structures, births, pregnancies, and poverty.

The quality of a dataset is determined by reliability (absence of mistakes), level of disaggregation (more disaggregate is better), level of geographical coverage (the more the better), level of social coverage (that is, it includes or represents all population and not just privileged groups), and level of detail (which depends on whether questions asked were varied and nuanced). The quality of socio-demographic datasets varies considerably from country to country. Typically, the more developed and wealthy a country is, the better its datasets.

Demographic variables that describe subjective preferences and views of individuals are not usually available and, if required, should be instead collected via original (even though sometimes relatively expensive) surveys.

6.2 Places

Places[5] represent the locations of opportunities[6] in which people wish to participate. These opportunities can be the jobs where people commute, the schools where parents deposit their children, and the stores where customers shop.

[5] *Places* are sometimes called *destinations*.

[6] *Opportunities* are sometimes called *activities* in the travel behavior field.

Locational datasets characterize the land use system, which consists of the amount, quality, and spatial distribution of activities (jobs, shops, health, social and recreational facilities, etc.), and possibly the times the activity is available.

Due to data limitations or unavailability, not every type of land use data is readily available. GIS datasets on activity location are available for many countries, with different levels of detail and coverage. Some tools use online GIS datasets for specific destinations (for example, locations of regional interest, such as airports, regional and national train stations, universities, and leisure facilities), but those data could be unavailable or expensive. In many access tools, to represent the number of reachable opportunities, socio-demographic data (as described in the previous sections) are used. Indeed most access tools measure the number of jobs accessible from a destination: the total number of jobs represents a proxy variable for workplaces destinations.

Places datasets can be collected from satellite image datasets[7] or land use maps.[8]

[7] See e.g.

- Bing Maps and
- Natural Earth

[8] See e.g.

- CORINE Land Cover

Private map services also sell detailed information for use in access analysis and tools.[9]

[9] See e.g.

- Thunderforest

In the UK, for example, most places datasets are derived from the higher education community the national mapping agency for Great Britain.[10]

[10] See e.g.

- Digimap
- Ordnance Survey

The following section discusses the various options that might exist for representing opportunities and provides guidance regarding potential trade offs for specific dataset choices. While vendors or databases may change, it is hoped the type of data they represent provide examples of options.

Opportunities can be represented in data in a few forms. The main groups of opportunities are:

- JOBS[11] datasets describe the distribution of jobs by sector provided by datasets. In the US, the Longitudinal Employer-Household Dynamics (LEHD) provides the most current, spatially detailed count of jobs. The jobs data are often tabulated by the workplace location, and the workers' residence location. For the purposes of an access analysis, jobs accessible

[11] The terms *number of jobs* and *employment* are considered synonymous in access analysis, (except in detailed analysis examining unemployment, vacancies, and labor markets) and describe the number of people holding jobs at the place of work. The number of *resident workers* sums workers by place of residence.

can be further subdivided by sector to represent access to services and retail, net total jobs, or other types of stratifications.[12]

Employment data should contain the number of jobs at a sufficient geographic granularity level (i.e. parcel, census block, census tract). Changes in number of jobs (i.e. new companies moving in, factory plant closing) in a region should affect the access results.[13]

More detailed and time-sensitive jobs data contains the temporal availability of jobs, which provides more accurate measure of access to jobs by time of the day, and contrast between the urban fringes and downtown locations. Job availability depends on the trip arrival time; use of this type of dynamic jobs data will also require more complex access calculation procedures.

[12] See
- LEHD Origin - Destination Employment Statistics (LODES)

[13] The access to job vacancies and unemployed people can also be analyzed, see (Fan et al. 2016).

- **People** data describe the geographical distribution of people by demographic group. These datasets are typically provided by sources such as the national Census or local planning or demographic organizations. These demographics can be further subdivided by the tabulations provided by the national Census or other studies to identify communities of concern or conduct different types of demographic analysis.

- **Points of Interest** (POI) and land use data refer to key non-employment, non-residential points of interest that serve specific trip purposes or provide a relatable and meaningful measures of access. Sources for this data can be crowdsourced data such as OpenStreetMap, parcel data from tax assessors, government inventories of community facilities, or be purchased from proprietary vendors. Real estate (housing and commercial property sales) data can come from local agencies, many jurisdictions in the US have a 'tax assessors' or 'parcel' file which includes many relevant variables. Often data are processed and organized by proprietary vendors.[14]

  Land use data contain the geometric information of land use objects, such as grocery stores, healthcare facilities, schools, shopping malls, and restaurants. It can be represented either by polygons or coordinates of the polygon centroids. Counting the number of land use objects located inside travel time isochrones, or the travel cost to the nearest points of interest are central to computing their access. Thus, the change of land use (i.e. building a new hospital or a new shopping mall) results in

[14] See e.g.
- CoreLogic
- Costar
- Multiple Listing Service

changes in access. The rate of land development also varies by locations. Analysis timeframe should consider the rate of change.

6.2.1 Characteristics of Opportunities

The data representing opportunities typically used for access analysis have two main characteristics:

- Granularity – The degree of spatial disaggregation of the data being used, granularity can represent opportunities by zones such as transport analysis zones (TAZs) and census geographies, or by much more disaggregated representations such as points of interests (individual points representing entities such a libraries or restaurants) or parcel data (commonly derived from a property appraiser office or other source). When the data being used to represent opportunities uses very large zones, an analyst needs to be aware of potential biases that can occur.[15]

[15] See the discussion on biases (chapter 5).

- Opportunity Attributes – The types of characteristics represented in opportunity data and its completeness are its attributes. For example, when working with US Longitudinal Employer-Household Dynamics (LEHD) jobs data, while the points are provided at the block level, it has complete attributes detailing the total number of jobs in each block and jobs broken down by sector. In contrast, if one is attempting to work with parcel data from a property appraiser, it is common to have an attribute such as building area and land use classification, but they may not always be complete or accurate. When dealing with incomplete data, consider filling in gaps or supplementing with other datasets.

6.2.2 Scenario Analysis

Like data for transport movement, data for places can represent scenarios – for example, changes to the spatial distribution of housing, employment, or points of interest. Strategic modeling teams at metropolitan planning organizations often produce land use forecasts several decades into the future. Access can also be used to determine the transport impacts of different land use forecasts resulting from different policy scenarios.

6.3 Movement

Transport networks facilitate movement of people and goods across multiple modes of travel. When we look at maps of road networks, they have facilities and details that are more important to some modes relative to others. A person on foot might be primarily interested in what sidewalks[16] or trails are available, while a driver might be more focused on which freeway entrance to use to merge onto the highway. This is to say, how we digitally represent travel networks for access analysis should consider who the traveler is, what their preferences are, and how they are reaching their destinations.

[16] The term *sidewalk* is equivalent to *footpath* in Oceania and *pavement* in the United Kingdom.

Traditionally, how we digitally represent networks draws from graph theory (the study of pairwise relationships between things), and thus road centerline networks maintained across the world heavily focus on the connections[17] between intersections.[18] However, for the purposes of access analysis, we should consider more aspects of network databases beyond this, including how the impedance or cost of travel should be represented for travelers and what aspects of the network are more relevant for different modes of travel.

[17] In the literature, these *connections* are often called *links*, *arcs*, or *edges*, depending on the intellectual tradition.

[18] In the literature *intersections* are often called *junctions*, *nodes*, or *vertices*.

Road network data are one of the core pieces in access computation. Routing algorithms need to be deployed on road networks to generate isochrones[19] for different transport modes (walking, biking, driving, and transit).[20] The ideal road network data records spatial information and travel time (or average speed and link length) for each link in the network. Changes in network topology (such as constructing a new road, adding a new transit line) and travel time (such as adding a new lane to the road, traffic signal time changes, more people sharing rides) generate changes in access results.

[19] *Isochrones* are the edges of *travelsheds*, and outline an area that can be reached in a given amount of time.

[20] The words *transit* and *public transport* are used interchangeably.

While in many places network topology and travel time change slowly, in others changes occur more rapidly. The data should be updated as frequently as needed for the analysis.

Movement data input for access tools include as key elements origin-destination (O-D) travel time or travel cost matrices, which can be expressed in terms of distances, time or costs. An O-D travel matrix measures the distance, the time or the cost for an individual to move between all origins and all destinations in the area of analysis using different transport modes. Building travel matrices requires the geography of transport networks and relative characteristics, which include performance indicators such as speed, time, reliability, and cost. Some of these indicators can be aggregated into more complex indicators, for example as generalized cost of travel, where travel time is converted into a monetary equivalent and travel cost (and any other type of cost that is considered) is computed as a single weighted value.

Most access tools use open data from OpenStreetMap (OSM), an open-access, collaboratively developed, street-level, global network database.[21] The most advanced access tools are permanently linked to the OSM database and therefore have the ability to be updated regularly.

[21] See: OpenStreetMap.

Travel times have historically come from magnetic loop detectors, installed by road management agencies in the road to measure speed and flow, and count travelers at intersections to control traffic signal timing timing. These data are generally, but unfortunately are not always, publicly available.

Some of the information considered by access tools, such as travel speed, is now provided on a real-time basis by GPS trackers and other navigation systems.[22] Pedestrian and cycling network data are also available at OpenStreetMap for calculating door-to-door travel times.[23]

[22] GPS data sources that provide road network speed and sometimes flow data and mode use data include:

- TomTom.
- HERE Technologies.
- Inrix.
- Uber Movement.
- Compass.
- DSpark

[23] See e.g.

- Open Cycle Map

which is based on data from the OpenStreetMap project.

Regarding datasets on public transport services, the most used sources are in the General Transit Feed Specification (GTFS) standard, which is a format for digitally representing public transport schedules and stop locations. Indeed, GTFS has become the standard for releasing public transit route and schedule data in many countries and has the advantage of allowing direct comparison of access levels in different cities around the globe.[24] GTFS lets public transit agencies publish their transit data and developers write applications that consume that data in an interoperable way. This standard facilitates efficient public transport analyses.[25] Real-time applications of GTFS allow the tracking of transit services as they actually occur, not merely how they were scheduled, allowing assessment of reliability.[26] Nevertheless, it might be difficult to use GTFS in some contexts, especially in countries with alternative proprietary mapping vendors.

[24] (Bok and Kwon 2016).

[25] More info on the GTFS and how to use it are available here. Software that can edit GTFS to build transit networks for access analysis include:

- TBEST.
- Conveyal Analysis.
- Remix.

[26] (Barbeau 2018).

Historically the GTFS standard was not compatible with flexible services that operate without fixed stops and structured timetabling, such as are available in many cities across Latin America, Africa, and Asia, where flexible transport services constitute a very high percentage of the available transport supply. The GTFS-Flex standard has been designed to accommodate such services.

In some cities transport agencies provide transport data, such as the Open Data User initiative by Transport for London (TfL). All TfL data are released for developers to use in their own software and services. TfL indeed encourages software developers to use its feeds to present customer travel information in innovative ways.

Innovative access tools make use of GPS real-time transport data. Data that are produced in this way deliver extremely accurate information about current system dynamics. Cell phones and other technologies have completely changed the way real-time data can be collected and shared, generating robust datasets from which overall patterns of service can be identified, for both car and public transport. Telecommunication companies are selling geospatial movement data for these purposes.

6.3.1 *Representation of Impedance*

When we discuss impedance in the context of access analysis, we typically refer to the cost (perceived or real) a user of the transport system experiences when they travel along a network. This can be represented in terms of the distance they have to travel, the time the journey takes, or include more complex representations such as monetary cost, energy required, or greenhouse gas emissions produced. Generally, network impedance may vary based on the following considerations:

- Distance Traversed. The most basic determinant of impedance is the distance traversed on the network, which affects the time, as travelers tend to prefer to reach destinations as quickly as possible, and this preferences the shortest path.[27] While the measure of distance in GIS can vary based on geographic coordinate systems, the most basic element of this characteristic is that, all else equal, travelers will find destinations further away more costly to access.

- Speed of Travel. Different modes have different assumptions with regard to their travel speed. This travel speed assumption ultimately influences the time a particular trip will take when considered alongside the distance traveled. This assumption may vary by mode, ability, or other network conditions.

- Temporal Conditions. Different times-of-day are likely to experience different travel network conditions that need to be accounted for in an access analysis. For example, while automobile access could be based on posted speeds for an access analysis, it might be more realistic to adjust for congested conditions depending on the types of opportunities someone intends to access or the time-of-day being assessed. Similarly, the

[27] Of course, for a variety of reasons, travelers often do not use shortest distance or travel time paths. (Zhu and Levinson 2015).

access provided by transit is highly schedule dependent. A user who misses the bus by 2 minutes might have a very different user experience and range of access relative to a user who arrived 2 minutes before the bus.

- Perceived Cost and Utility. To be more realistic, to account for comfort or traffic stress, or to model more complex aspects of access requires adjusting the network based on its utility or value provided to a particular traveler. This might be as simple as modifying the impedance of a bicycle network to decrease effective speed on high-stress roadways, or as complex as modeling the monetary cost of travel choices by integrating transit fares, parking charges, and road tolls into an access analysis.[28]

  For instance, transit travel time components include transit stop access time (travel time between the origin and a transit stop), transit stop waiting time (waiting time at a transit stop until the arrival of the transit), in-vehicle travel time (travel time spent in a transit vehicle), transfer time (time spent during transit transfer), and egress time (travel time from the the final transit stop to final destination). The value of time during different stages of transit travel should be treated differently. A traveler is able to read, work, social network, play games, and watch videos while waiting at a transit stop and traveling in a transit vehicle, but often is less productive during the time spent accessing a transit stop from an origin, transferring between transit vehicles, or egressing from a transit stop to a destination .

[28] (El-Geneidy et al. 2016).

- User vs. Full Cost. When computing access with the consideration of monetary cost, we need to differentiate user cost and full cost. User cost is the price that a user actually pays for a trip, including travel time, and perhaps some allocation of fixed costs such as costs of purchasing vehicles, vehicle maintenance, insurance, and fuel. Full costs include user costs, the costs of providing infrastructure which are not borne by travelers, plus externalities. Almost all transport agencies receive subsidies from the public and all travel generates externalities, so user cost is generally lower than full cost.[29]

  The choice of cost depends on the rationale for the analysis of access. If the access metric is used to evaluate access of individuals, the user cost is recommended. If the access metric is used by municipalities and metropolitan planning organizations

[29] It depends on the country, in some countries, for instance, the fuel tax borne by vehicle travelers exceeds the social cost of travel, and so user cost would be higher.

for transport planning and management, the full cost should be used.[30]

[30] (Cui et al. 2019, Cui and Levinson 2018b).

- Reliability and Variability. Reliability refers to the percentage of time when the travel time is acceptable. All modes have reliability issues, auto and transit more than others. Transit isochrones computation results are affected by transit vehicle frequency, time-of-day, and even day-of-week. A transit isochrone computed right before a transit vehicle arrives could be larger than the one computed right after a transit vehicle leaves. How big the difference depends on the transit vehicle frequency. Since the transit frequency and schedule varies by time-of-day and day-of-week, an isochrone computed at one time point might not be representative. A common solution is to sample multiple time points and compute average travel time across the sampled time points.

This section highlights possible scenarios for representing impedance based on practitioner knowledge of relevant datasets and existing literature regarding common assumptions and existing best practices. The guidance provides practical implementation strategies for multimodal access analysis. The mode-specific data requirements that are described below evaluate the necessary data along the following dimensions:

- Granularity. The degree of network detail required. This reflects the fact that some modes can realistically represent their range of access with differing degrees of network detail. For example, while residential streets may have only a small influence on access calculations for traveling by automobile, they can have large impacts on bicycle or pedestrian travel as they can represent facilities where significant portions of a trip are occurring on.

- Network Attributes. Network characteristics that relate to the speed possible by the mode or those that may influence its cost in other ways.

- Temporal Conditions. Whether network conditions or costs change with time. This change can result phenomena such as automobile congestion or a transit rider missing a scheduled bus.

- Geometric Accuracy. The quality of the representation of the travel network.

- Scenario Compatibility. The ease with which the network data can change to represent new scenarios for analysis. Some modes involve network components that are intrinsically more complex to represent, and some measures of utility or cost can change based on the prevailing conditions of the network.

Each mode under discussion has a data requirement summary list. These lists summarize high level descriptions of the data considerations for conducting a best practice access analysis for a particular mode. These lists describe the considerations for best practice access analysis for a particular mode given below.

6.3.2 Walk

This section outlines the data considerations for networks intended to model access for transport system users traveling by walking.

- Granularity. Walking requires the highest degree of network connectivity and granularity for non-highway routes. Ideally, a pedestrian network would include trails, local roads, and other facilities pedestrians can traverse, and identify sidewalks and shared spaces.

- Network Attributes. Pedestrian attributes at minimum should include where pedestrians are allowed or not (no traversal is possible on highways). At best, they include whether there are sidewalks available, slope, and relevant adjustments to impedance that account for potential changes in traffic stress on very large arterials (to account for route preference/perceived costs). Additionally, very detailed analysis for pedestrian network modeling would account for crossing locations. Speeds rarely have to be associated with the network, and a typical assumed speed for pedestrians is 5 km/h (3 mph).

- Temporal Conditions. Pedestrian access analysis typically does not require adjusting based on temporal conditions. In downtown locations with very heavy pedestrian traffic, this assumption should likely be reconsidered.

- Geometric Accuracy. A best practice pedestrian access analysis requires a high degree of network geometric accuracy and tested connections between trails and local streets.

- Scenario Compatibility. A pedestrian network is relatively easy to represent across different scenarios as adding and removing links is a relatively straightforward process that does not require running a strategic planning model[31] to identify potential changes to impedances.

[31] *Strategic planning models* are often called *travel demand models* (TDM) or *urban transportation planning model systems* (UTPS), among other names. Many are classical *four-step planning models*, though newer ones employ *activity-based* or *agent-based* models (ABM). For the purposes here, the point is that they can produce outputs like origin-destination travel time matrices which can be used for access analysis.

Modeling pedestrian behavior requires detailed network and attribute data to accurately model pedestrian conditions, but it does not require much accounting for temporal conditions due to congestion and is very easy to represent across scenarios. Generally, the most important attribute to include in this analysis is which facilities have restricted access such as highways or ramps.

However, very high end pedestrian access analysis would account for features such as sidewalk availability, street crossing locations, and the quality of the pedestrian network using measures that adjust for comfort or perceived utility. Delay caused by traffic signals can significantly reduce measured walking access, but such effects can be difficult to model using only the pedestrian network. This degree of analysis requires representing the network with sidewalks on both sides of the street, integrating crosswalk locations into the network, accounting for potential signal delay / crossing time into the analysis, and potentially adjusting impedances of streets based on pedestrian comfort. Integrating any of these elements can increase the complexity of analysis, but can add value during scenario evaluation phases where improvements that benefit specific populations (disabled populations for example) or address pedestrian comfort can be incorporated.

Increasingly, comfort-weighted impedances for pedestrian access are being applied as part of pedestrian access analysis, but there is no agreement on how much weighting is appropriate or if high-stress streets should be treated entirely as barriers in analysis. As a rule of thumb, while a speed of 5 km/h (3 mph) for walking speed is generally used for pedestrian access analysis, this assumption should be reevaluated if the questions being addressed require a different perspective on how pedestrians perceive the network or whether that speed is appropriate for a specific demographic group's abilities, and how traffic signals are treated, since they add significantly to pedestrian travel time in urban areas. Adjusting the speed to account for traffic signals (or lack thereof) is a way of simplifying this analysis.

6.3.3 *Bicycle*

This section outlines the data considerations for networks intended to model access for transport system users traveling by bicycle. This section also discusses how to model access for other emerging micromobility modes such as scooter or e-bike.

- Granularity. Bicycling analysis requires a granular network that would include trails, local roads, and other facilities bicyclist can traverse.

- Network Attributes. Network attributes at minimum should include where bicyclists are allowed or not (no traversal is possible on highways or pedestrian-only facilities), and whether or not the streets are one-way. At best, they include slopes, whether there are bicycle facilities, and relevant adjustments to impedance that account for potential changes in traffic stress on very large arterials (to account for route preference/perceived costs). The inclusion of metrics that relate to traffic stress might include information related to the number of lanes, posted speeds, bicycle infrastructure availability, Annual Average Daily Traffic (AADT), and other contextual data. Bicycle speeds are often assumed to be independent of auto speeds and road type, and thus may be slower than traffic on arterials in uncongested conditions, and faster during congestion, as bicycle can filter through traffic. A typical assumed speed for bicycling speed is 16 km/h (10 mph). More advanced analysis may integrate the impacts of slopes into an access analysis, as they have been demonstrated to influence active travel.

- Temporal Conditions. Bicycle access analysis typically does not require adjusting based on temporal conditions.

- Geometric Accuracy. A best practice bicycle access analysis requires a high degree of network geometric accuracy and tested connections between trails and local streets.

- Scenario Compatibility. A bicycle network is relatively easy to represent across different scenarios as adding and removing links is a relatively straightforward process that does not require any intensive modeling to identify potential changes to impedances (such as running a strategic planning model).

Models that evaluate different impedances based on changes in traffic stress will require adjustment based on assumed changes to facilities. This can increase the effort it takes to model scenarios for bicycling access as it requires the representation and management of impedances distinguishing high- vs. low-stress facilities.

Micromobility

There is no fixed definition for the term *micromobility*, but there is some consensus around its reference to the use of vehicles that are compact, light-weight, and commonly electrically powered in some shape or form.[32] These vehicles have the potential to increase the acceptable ranges of a trip relative to existing active modes of transport by increasing the convenience, decreasing the travel time, and reduce the physical effort required to complete a trip. These vehicles potentially mitigate the impact of unfavorable terrain and topography on active modes of transport. All of this would need to be considered when evaluating how powered micromobility would impact access. There is disconnect between the presumptive speeds of micromobility vehicles, typically in the range of 25 km/h (15 mph), and emerging definitions putting the top speeds of e-bikes and scooters as high as 50 km/h (30 mph).[33] In general, more research will be required to identify appropriate methods to compare the utility of these emerging modes relative to well understood ones such as bicycling and walking. For example, the level of traffic stress framework still applies to micromobility, as micromobility users experience similar degrees of traffic exposure as bicyclists.

[32] SAE International (2019).

[33] (SAE International 2019).

Bicycling access and connectivity is undergoing a great degree of study as metrics such as Level of Traffic Stress (LTS) are increasingly being used to create a realistic understanding of bicycle access.[34] Other emerging data standards for bikes, such as the General Bikeshare Feed Specification (GBFS)[35] describing the status of bikeshare systems in real-time has the potential for wider adoption, and in facilitating the use of micromobility services.

[34] Mekuria et al. (2012).

[35] GitHub Project (2020)

6.3.4 *Measures of Low-Stress Cycling Connectivity.*

Increasingly, Level of Traffic Stress (LTS) is becoming the mainstream metric of choice to identify what roads are considered to be preferred for use by the general population. Bicycling access and connectivity is undergoing a great degree of study as metrics such as LTS create a more realistic understanding of bicycle access (Harvey et al. 2019, Mekuria et al. 2012, Murphy and Owen 2019a, Wasserman et al. 2019). The idea behind incorporating some type of LTS metric for bicycle or similar modes is based on the recognition that one of main barriers to bicycling is oriented around the perceived comfort and safety of traversed facilities (Harvey et al. 2019). While a number of LTS generation metrics have arisen since the first paper on LTS in 2012, the similarities between them tend to center on arterials with higher speeds and flows requiring distinct levels of separation to increase comfort and safety on those facilities (Harvey et al. 2019). The choice of metric is an area of active research (Harvey et al. 2019). When modeling how LTS relates to access, several approaches have been observed in practice. Some of the modeling methods used include:

- Connected Islands. Informed by the first papers on LTS, one of the approaches used when applying LTS to access is identifying the size and scale of connected *low-stress islands* (Mekuria et al. 2012, Wasserman et al. 2019). These islands represent locations where people can reach destinations from just using low-stress islands, and highlight how higher order arterials and other facilities can act to *fragment* an urban area. In many ways, this approach models bicycle connectivity in terms of how larger facilities act as barriers to bicycling just as highways fragment ecosystems or hills delineate watersheds.

- Impedance Adjustment. Other approaches model low-stress connectivity using conventional representations of access by comparing augmented *reachability* measures by adjusting the impedances of traversing high-stress segments. The approaches for this vary, but approaches that try to mitigate the impact of misclassified LTS segments have been used for practical reasons. For example, Conveyal adjusts impedances so that on high-stress segments, users are assumed to walk 5 km/h (3 mph) rather than ride 16 km/h (10 mph) in order to model low-stress access (Conway 2015). In the case of OSM-derived Level of Traffic Stress metrics, this can be an advantage in that it provides an augmented access measure that captures macro-level trends in low-stress access while not being overly sensitive to misclassified LTS scores (Conway 2015). This contrasts to approaches that adjust high-stress segments so that they are essentially impassable. (Mekuria et al. 2012). This barrier approach should be used carefully however as it can be highly subject to start location bias (section 5.4) and misclassified LTS scores on the network (Mekuria et al. 2012).

- Acceptable Diversion. Another approach to modeling low-stress access is measuring the degree of diversion required to complete a trip using low-stress segments relative to some baseline alternative. For example, a Bicycle Network Analysis tool considers two locations connected if the diversion distance is less than 25% of that of a trip using a car, and if there is a low-stress route completely connecting the two locations (People for Bikes 2015). This use of diversion rate provides a useful cut off for low-stress connectivity analysis by explicitly comparing paths to alternatives travel modes or relative to using all segments on a bicycle network.

Each approach has advantages and disadvantages. More research is needed to determine which approach better reflects the mode shift potential, actual trip taking behavior, and traveler decision making processes. In addition, whether the added value from the more complex approaches justifies the additional complexity needs to be determined beforehand.

6.3.5 Automobile

This section outlines the data considerations for networks intended to model access for transport system users traveling by automobile.

- Granularity. Automobile access generally has less detailed network requirements than other modes, as it can be computed on simplified or coarse networks with less relative error as long as major highway and arterials are represented in the network dataset. This simplified representation was once common in strategic planning models for example, when data was scarce and computation expensive.[36]

[36] However this type of representation in models reduces accuracy as it results in modeling artifacts like oversaturating some links due to exclusion of others, and increases the number of iterations required for equilibration, and is poor practice with modern data and computation capabilities. While it may have been acceptable practice in 1955, we doubt it remains so in the 21st century.

- Network Attributes. The key network attributes for automobile access are related to posted speeds, one-way behavior, congested travel speeds, where cars can drive (excluding trails/sidewalks), and the functional classification of the streets.

- Temporal Conditions. Automobiles are subject to congestion on roadways, and thus speeds that are possible will change over time. These changing temporal conditions are computationally intensive to capture using strategic planning models, and can be expensive to derive from GPS data from vendors at the scales required for auto access analysis.

- Geometric Accuracy. It is important for higher order facilities such as arterials and highways to have the appropriate connections. Inaccuracy on lower order facilities has less impact on overall results.

- Scenario Compatibility. Representing scenarios with regard to potential improvements typically requires using a model to identify how changes in conditions alter congested travel times. Other approaches might be a literature review to determine appropriate elasticities for potential improvements for a quick response understanding of the impact of potential changes.

Congested vs. Non- Congested Analysis. Modeling automobile access with real world data can be a real challenge because the places one can reach become more constrained when travel conditions are congested. Thus, automobility access analysis tends to be done in primarily two forms:

- **Non-congested analysis.** Where posted speeds[37] determine how quickly travelers can reach their destinations.

- **Congested analysis.** Where congested speeds determined for a specific time-of-day are either modeled or derived from GPS data to determine how quickly and thus how far a traveler can reach on the network.

While a non-congested analysis might require some basic information such as posted speeds and one-way behavior, congested analysis can be more difficult to model in practice as it requires either deriving congested speed information from travel demand models or from real world GPS data.

[37] Sometimes 'freeflow speeds' are used. In a world with good road design and effective traffic enforcement, posted and freeflow speeds should be the same. Enforcement varies by location.

6.3.6 Transit

This section outlines the data considerations for networks intended to model access for people traveling by public transport. The data for public transit access and egress modes is discussed in sections on walk, bicycle, and auto above.[38]

[38] subsection 6.3.2, subsection 6.3.3, and subsection 6.3.5.

- **Granularity.** Transit requires a relatively granular street network dataset to realistically represent pedestrian connectivity to stops. However, some crude access analysis is possible using just the transit schedule, route, and stop data alone when the assumption is pedestrian travel occurs using crow fly buffers. Recognizing step-free access for the physically disabled is also critical. As shown in Figure 6.1 much of the London Underground and Trains network are inaccessible by wheelchair, particularly those parts of the network built before the 1980s.

- **Network Attributes.** Transit requires both detailed pedestrian network and transit attributes. The pedestrian network requirements are described above. The transit network typically requires an understanding of the relationships between the transit route, stops, and schedule.

- **Temporal Conditions.** Transit data, when represented in an access analysis is highly temporal as it is commonly determined by the schedule data in GTFS. Variance can occur in travel access as a result of changing frequencies of transit across longer time periods, or as a result of changes in instantaneous access that result from user wait time at stops. Generally, high frequency and redundant transit networks tend to have less variability in transit access across time relative to lower frequency networks.

- GEOMETRIC ACCURACY. A best practice transit access analysis should include accurate transit network data from up-to-date GTFS, and should include a pedestrian network that includes good connectivity between trails and other streets.

- SCENARIO COMPATIBILITY. Transit network data are one of the hardest to represent in a scenario-oriented manner if one is modeling transit using scheduled based analysis as it typically requires editing and reimporting GTFS for further analysis.

Transit access analysis can be one of the more complex forms of access analysis as a result of its schedule dependence and the need to accurately model pedestrian behavior. While approaches have been developed to simplify the characteristics of analysis by converting a schedule into average route speeds and wait times or simply ignore the pedestrian network, there are trade-offs to consider when evaluating different ways to approach transit analysis.

1. SCHEDULED VS. ON-DEMAND SERVICE (I.E. DIAL-A-RIDE, PARATRANSIT). Scheduled and on-demand transit services are both transit, but they differ by nature. On-demand transit service has historically focused on elderly and special needs populations, and its service had been determined by user requests, with advanced scheduling required. With the advent of the software and network economies underlying ride-hailing services, on-demand has become more feasible, and expectations for scheduling in advance have disappeared. Recently it has been expanded to serve low density public transit markets as a last-mile type of solution. Some on-demand transit systems provide door-to-door service, while others serve as paratransit and only connect travelers to transit stops. The challenge of computing access for on-demand transit service is the lack of travel time and waiting time data. In most cases, the boarding and alighting data is manually recorded by drivers. The accuracy and quality of the data is also questioned. In addition, it is very difficult to quantify the cost of on-demand transit service.

2. TRANSIT TRIP PARAMETERS. There are a few parameters, including number of transfers, transit sub-mode preference, walk

speed, and maximum walking distance, that need to be set up prior to transit isochrone computation. Based on the observation in most US cities, more than 90% of transit trips have no more than two transfers.[39] A rule of thumb for access and egress walking speed is 5 km/h.[40] Maximum walking distance varies by which country travelers live, and should be informed from observed data (e.g. 95^{th} percentile of travelers' walking distances).

[39] (Owen and Murphy 2018).

[40] This is also the default setting in OpenTripPlanner, an open source transit isochrone generation tool.

3. PARK & RIDE. The scenario of park & ride, where travelers access transit by driving to transit stops and stations and store their cars is more complex to compute transit isochrones and more factors need to be considered. Real-world network travel speed or travel time data needs to be integrated with GTFS data. Parking time and cost need to be taken into account when calculating total travel time and cost. Parking availability is a major constraint that affects traveler's decision on whether or when to drive. Kiss & ride, where a passenger is dropped-off, and the driver continues to another destination, is similarly complex.

6.3.7 Freight

While access metrics have been less frequently applied to freight, it is worth discussing the potential approaches, applications, and considerations when conducting a freight-oriented analysis. In analyzing freight access, the movement is produced by the freight vehicles to reach people or other destinations. GDP or the number of firms can represent the value of market at the destination (or serve as attraction for freight), which substitutes for the amount of opportunities in the traditional person-based access; the cost of transport represents travel impedance.[41]

[41] (Jeong et al. 2020, Simmonds and Jenkinson 1993; 1995).

Some transport infrastructure, such as highway networks, are shared among person and freight transport. Freight analysis must reflect that certain links prohibit certain types of truck traffic, and other links are truck-only. In addition freight analysis may want to consider rail, shipping, aviation, and pipeline networks if appropriate.

- GRANULARITY. Similar to automobile access, freight access is generally less impacted by being computed on simplified or coarse networks as long as major highway and arterials are represented in the network dataset. This simplified representation is often common in strategic planning models for example. An exception is urban freight and last-mile delivery services, which require highly granular networks.

- Network Attributes. The key network attributes for freight access are related to the presence of freight routes, posted speeds, one-way behavior, congested travel speeds, height limits, where trucks can drive (not trails/sidewalks), and the functional classification of the streets. Urban freight and delivery services may additionally require information about parking and curb-use restrictions.

- Temporal Conditions. Freight transport operations generally occur at different times than human transport. Road freight transport is subject to congestion on roadways; rail freight operations often need to negotiate limited railway capacity with passenger rails. Freight trucks are restricted from entering CBD of some cities during daylight hours, to preserve road space for passenger cars. These changing temporal conditions are computationally intensive to capture using strategic planning models, and can be monetarily expensive to derive from GPS data from vendors at the scales required for freight analysis. However because a large number of links are prohibited to certain kinds of freight traffic, other aspects of the analysis may be computationally less intense.

- Geometric Accuracy. It is important for higher order facilities such as arterials and highways to have the appropriate connections. The inclusion of local facilities is likely not necessary, but prioritizing their accuracy in industrial locations and hubs might be worth examining.

- Scenario Compatibility. Representing scenarios with regard to potential improvements typically requires using a model to identify how changes in conditions alter congested travel speeds for detailed analysis of changes, however other aspects of freight access analysis may not require extensive modeling while still having useful applications. For example, examining a change in designated freight routes potential impacts on access to delivery locations or hubs could provide a high level understanding of improvements.

Routing analysis for freight is critical to logistics and delivery companies. While access is an analytical frame typically reserved to policy or siting, there is likely a benefit for cities and regions examining their network from an operator's perspective and proactively ensuring planning decisions do not have an undue burden on a this component of the economy and the transport sector.

Access analysis for freight could build an understanding of how preferred routes interact with pick-up and drop-off opportunities, their access to industrial land uses and warehouses, and other relevant opportunities to the logistics industry. Being able to model freight opportunities given a region's freight policy is likely to become increasingly important as deliveries continue to grow and modify the the types of trips people take. It is possible that databases that relate to curbside regulations and rules from specifications like CurbLR[42], for example, could provide a source of opportunity data for understanding how different curbside management policies could impact freight. In addition, freight routing could be tested with the perceived costs or determined utilities of non-freight routes being adjusted to be higher relative to freight routes.

[42] CurbLR is an emerging standard promoted by the organization SharedStreets.

6.3.8 Scenario Analysis

Metropolitan Planning Organizations (MPOs) dedicate significant resources to maintaining strategic planning models intended to forecast future demand's impacts on the travel network during different times-of-day.[43] These models can be rich sources of information for automobile access computations in that they can either provide congested skims (Origin-Destination matrices) between different locations from which access can be calculated very easily or they can provide 'loaded' networks whose representation of congested travel speeds can be incorporated into another platform for analysis. These are especially important for estimates of future access, when measured data are not available.

[43] (Twaddell et al. 2018).

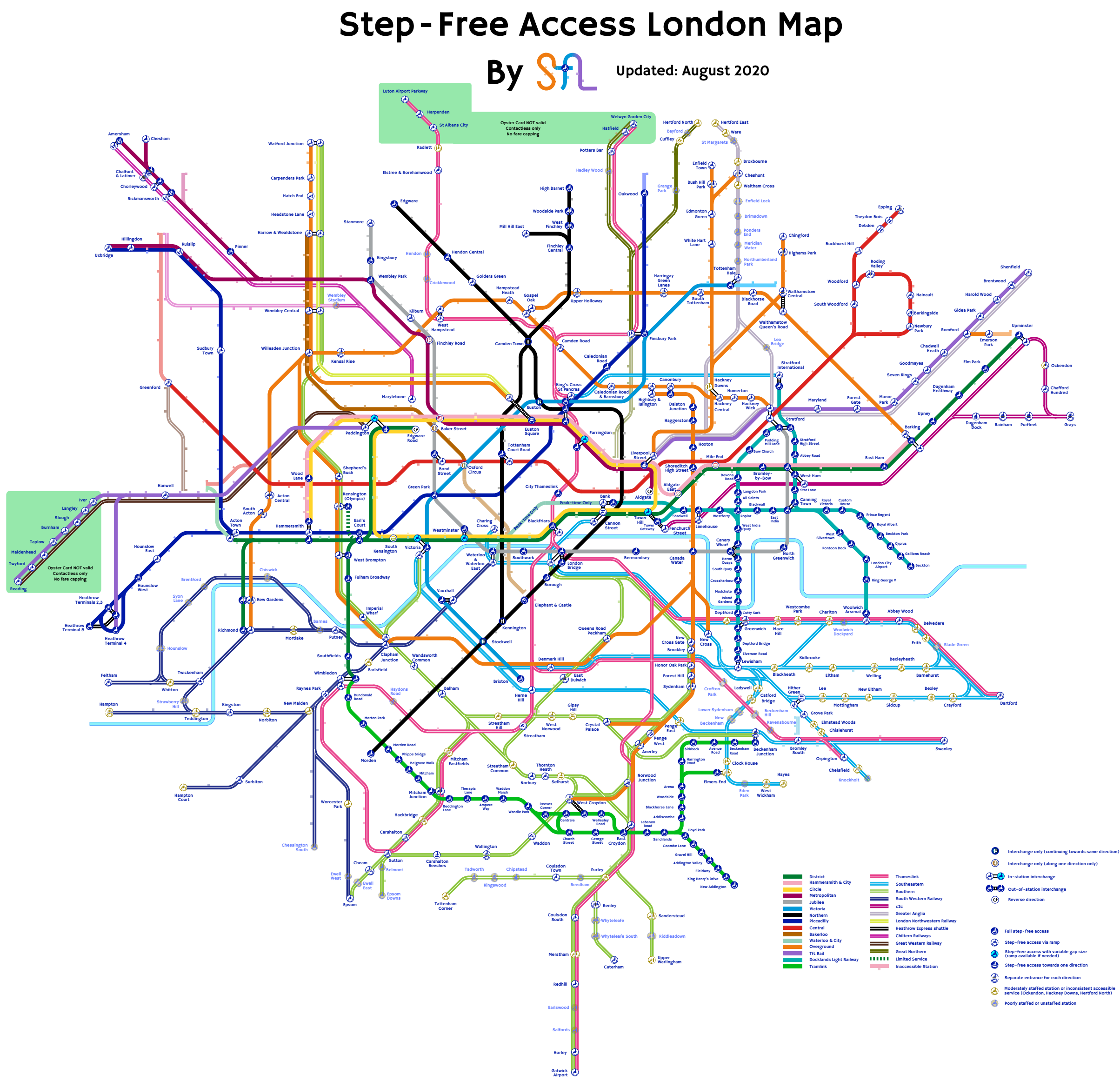


Figure 6.1: Step-Free Access London Map By Step-Free London. Created by Tomas Rey. Used with Permission.

6.4 *Time*

Data that simultaneously present not only what and where activities take place, but also when, can be extremely useful for access planning.[44] Temporal data refers to the availability of activities at different times of the day and the time available for individuals to participate in certain activities. Time use databases for access would enrich the demographic dataset by adding the time schedule of individuals, and enrich the spatial dataset by adding to the time distribution of services and activities. Access tools that run on temporal data are necessarily data-hungry, as each location and individual need to be associated with detailed descriptors of what is happening as time passes. To gather this type of data, one can use digital devices that continuously register where people or vehicles are located, where a certain service is being provided, or when a certain facility is operating. Some studies have been based on databases filled using travel diaries, in which people write at regular intervals what they are doing, where they are doing it, and how they got there.[45]

[44] (Hagerstrand 1970).

[45] (Eyer and Ferreira 2015).

Practitioners have benefited from using access tools operating with time-space databases, as these provide detailed insights on access issues. The visual potential of time-space geographical databases is another selling point, as good graphics help to create refined presentations with potential to attract attention and generate curiosity.

6.5 *Financial*

Financial data for access tools are highly valuable for understanding the relationship between service demand and transport supply, but the data are often expensive and difficult to collect.

Datasets on fare schemes, operating revenues, aggregate costs, and household income are available in some countries from the public transport agencies or national data repositories.[46] In addition, since most mass transit and roadway management responsibilities fall to public agencies, financial data can be acquired through a combination of web searching and internal records requests. However, this kind of data access is not guaranteed nor necessarily easy to obtain. Widely used private data like regional gas prices can be acquired through web scraping. Finally, per the national censuses mentioned above, most demographic databases include income data.

[46] In the UK, for example, all data are online and freely available at the statistical dataset web portal.

Much financial data either do not exist, are proprietary and so unavailable, or are technically difficult to consider alongside related data. Consider an urban area with major fixed investment needs. How would the relevant local government's lending rates be acquired, since they're often behind financial service firewalls? How would a tool know how to price major capital projects like highways or transit lines that can vary significantly based on length and other details? Are there established elasticities to determine how much the pricing of new services would impact new customer levels?

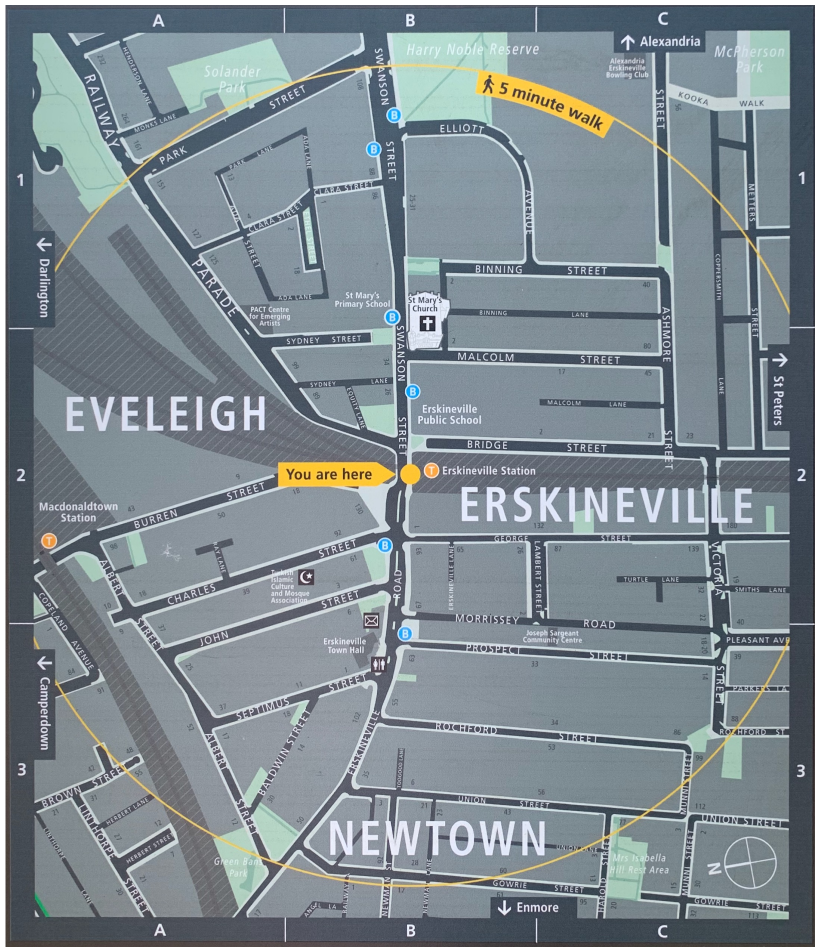


Figure 6.2: An information pylon near Erskineville Station in Sydney shows a 5-minute walk isochrone and key destinations therein. Notice north is not up.

7
Futures

One strength of viewing and evaluating transport systems from an access perspective is that this framework is robust to future technological transformations. It is possible that technology could dramatically reduce some of the prime transport issues of our day. Automated vehicles could vastly improve transport safety. Electric vehicles could dramatically reduce vehicle-based carbon emissions. Automated vehicles, could, at least in theory, reduce congestion. So some of the concerns, and our corresponding measures of performance, of our current transport system may become less relevant over time. However, access is a fundamental concern of transport and therefore will continue to remain relevant.

No matter what modes or technologies prevail tomorrow, transport will still involve costs in time and money. Transport will still involve connecting people to places. As long as people need to engage in travel to participate in the full range of activities that are part of life, the framework of access and access-based evaluation will remain relevant to understanding transport and land use systems.

7.1 *New and Emerging Travel Modes*

This section reviews recently emerging or anticipated technologies that are anticipated to have an impact on access. We do not strive for a comprehensive review of such technologies and their social impacts, but rather we focus on how such technologies might influence access, and which groups stand to benefit or may be excluded.

Access historically has referred to the ability to physically reach destinations to do things that can only be done there. Its meaning has been broadened, as with virtualization, many activities can now come to the participant. Access opportunities encompass essential goods and services (education, employment, basic shopping, healthcare) as well as to other destinations that provide meaning or happiness (social community, parks and recreation, etc.)

Understood in this way, access is something that humans have always needed and will always need.

Many new transport technologies and strategies are being invented and tested. Sharing is an important buzzword. Humans have always shared the road, different people and vehicles use the same space at different times. Much of the innovation in the 2010s was around expanding ways to share resources, including both sharing rides (ride-hailing services alongside what public transport has always done) and sharing vehicles (bike-share, car-share, etc.) The prospect of autonomous vehicles (AVs) remains on the horizon. All of these inventions require refining how access is described and calculated. This chapter reviews these areas of innovation, and how they are likely to affect the concept of access, and the process of measuring it.

Working from home (WFH) (telework or telecommuting) has increased sharply due both to advances in information and communication technologies such as wireless and broadband internet, as well as reluctance and restrictions on travel associated with COVID-19. The pandemic forced a switch to a work-from-home mode for many organizations that had never intended to, and that had assumed it was impossible. This caused telecommuting tools to be rapidly improved and scaled up, which is a permanent change. Some organizations and workers have found that telecommuting works better than expected, so it is possible that many commutes have been permanently removed from the system. The implications of this for access are significant, as even a few days a week of telecommuting reduces the need for high physical access (the time saved by not commuting on Tuesday can be spent on a longer commute Wednesday), and thus likely weakens the effect of access on residential land value. Full-time telecommuting would weaken this relationship even more, as physical access to the job would no longer be as significant a constraint on home location, high-speed internet access may be sufficient.

E-Commerce and delivery are changing how individuals access goods. While ordering goods directly without going to a store has existed for well more than a century (catalogs, mail, and phone orders; raw and prepared food delivery; door-to-door sales) internet shopping is bringing it to a whole new level. Furthermore new ways of delivering goods such as drones and mini robots are being developed. E-commerce can improve access to goods in that the choice of items is usually more extensive in an online catalog than in a physical store and an individual can peruse multiple websites from a single computer instead of travelling to a variety of merchants, possibly in different locations. This does not necessarily eliminate the need to access any brick and mortar stores but creates additional options and can reduce the need for some trips.

Electric vehicles (EVs) are taking market share from internal combustion engines. In concept how a vehicle is powered has no impact on access. To the extent EVs have less range and fewer options to charge up, this could constrain an individual's ability to access some destinations. As the technology of EVs improves and charging options become more prevalent, the constraint will be less binding. Indeed since charging occurs when a car is normally parked it eliminates the need for trips to service stations for refueling. Shared EVs will need down time to charge, but this should not impact an individual's opportunity for access unless there is a shortage of vehicles available at a particular time.

Car-sharing consists of a fleet of vehicles that can be used by individuals who generally pay on a per-use basis or per mile basis. Generally found in dense urban neighborhoods, car-sharing allows households to be car free or own fewer motor vehicles yet provides the flexibility of having a vehicle available when walking, bicycling or transit are not viable alternatives. In some cases a variety of vehicles are available so individuals can use the vehicle most suited for a specific trip purpose – for example a larger vehicle when needing to haul large items. It does however incur a larger access/egress time than private vehicles as well as higher per trip costs.

SMARTPHONE APPS continue to be developed that streamline payment between different transport providers and provide trip planning information. These apps can have a significant impact on access as they enable individuals to determine the best path to take, the best mode to use, and the estimated cost of a trip, and can simplify payment.

RIDE-HAILING companies have disrupted the taxi industry by streamlining and simplifying the trip booking and payment process. Individuals can book a ride anywhere, anytime in places that ride-hailing companies operate, with usually little delay before they are picked up. They know in advance the cost of the trip. However ride-hailing companies have come under considerable criticism for the ways that they may actually be impeding access. Because no cash is exchanged, ride-hailing companies may be unavailable to individuals who are unbanked. Most vehicles cannot accommodate wheelchairs or other mobility devices precluding many individuals with physical disabilities from using the service. The low fares are not sustainable with current labor structures – ride-hailing companies are losing billions of dollars per year; therefore prices will either increase dramatically making the service unaffordable to more users, services will be curtailed, or vehicles will be automated. Research is beginning to demonstrate that ride-hailing companies are increasing congestion and decreasing transit ridership.[1] The ultimate impact that ride-hailing companies have on access is unknown. As discussed below, AVs will have an impact and the distinction between car-sharing and ride-hailing companies will blur.

[1] See (Erhardt et al. 2019, Graehler et al. 2019), contra (Hall et al. 2018).

MICROMOBILITY has grown rapidly in recent years. Micromobility, a range of new modes enabled by combinations of information and battery technologies, began to coalesce with docked bike sharing, where a bank of bicycles would be docked at designated locations throughout a community. Micromobility has expanded to include dockless bike sharing, electric bikes (of various styles, including unicycles and cargo bikes and tricycles) (both shared and privately owned), scooters and electric scooters and skateboards and Segways, as well as subsuming the traditional bicycle (which is just an e-bike without a battery). Micromobility sharing services are found not only in large cities, and now appear in smaller communities including lower density suburbs.

At its essence, micromobility means traveling faster than you can walk without taking much more lateral space than your body does. As such, they are a more effective way for large numbers of people to move in a city, where there is not much space per person. This in turn means that more people can potentially achieve higher access (in terms of travel time) before the limits of congestion are reached. These tools are inexpensive, requiring neither an expensive car nor a paid driver, and can therefore also provide access at low cost.

While use of a micromobility sharing service may replace some transit trips they also are a great way to reach transit services providing first and last mile access. Transit access could be improved, for example, if micromobility took on a greater proportion of short trips, allowing transit to specialize around longer ones – for example through wider stop spacing. Despite the benefits of micromobility sharing, there are issues that need addressing. As with ride-hailing companies, these services may not be available to unbanked individuals. Docked sharing tends to concentrate in more affluent parts of cities – this is also an issue for dockless systems. There are safety concerns including injuries from falls and collisions with pedestrians as well as vehicles. Individuals leaving dockless bikes or scooters in the middle of sidewalks or other inappropriate areas have been another concern.

Access for shared micromobility, like car-sharing, is somewhat more complicated to compute than access for other modes, as the shared vehicle needs to be collected and deposited, and those locations are dynamically changing.[2] Privately-owned micromobility has similar access issues as bicycles, though the speed of travel and willingness to share streets with with automobiles may differ.

[2] (Schoner and Levinson 2013).

AUTOMATED (OR AUTONOMOUS) VEHICLES (AVs) will disrupt mobility and may have both positive and negative impacts on access. However the pace of change and the actual impacts of change are unknown. Supporters of AVs envision the technology will improve safety, reduce congestion, and provide access to individuals who can't drive. Ride-hailing companies are counting on AVs to reduce operating costs to enable profitability while maintaining a low price structure. Some experts envision AVs will be primarily shared resulting in significantly lower auto ownership and in essence blending the car share model with the ride-hailing model. Another claim is that widespread use of AVs will significantly reduce the need for space devoted to auto storage and movement. A contrary prediction is that as AVs become more common, vehicle travel will grow dramatically resulting in severe congestion and increased decentralization of the population. How AVs react to the unpredictability of humans walking or riding scooters or bikes, and whether that results on additional restrictions on pedestrians and bicyclists, will affect those engaged in active transport, though whether that is worse than human drivers remains to be seen.

Automated methods of moving individuals (such as elevators, escalators, airport people movers or automated transit systems) typically operate in a closed environment. There will be a long period of time before non-autonomous vehicles disappear or become banned. How AVs function in an open, mixed system is a big unknown.

SHARED AUTOMATED VEHICLES (SAVs) are perhaps a natural convergence of automation with sharing. This would be something like current ride-hailing vehicles, but with automated drivers. Automation is made more affordable through sharing; shared mobility is made more convenient through automation. Researchers have studied SAVs primarily through simulations. The outcomes of these simulations depends largely upon the assumptions made about how such systems will work and how people will respond to such transport offerings. For example, one study of SAVs predicts greatly increased access through the entire city,[3] while another study predicts reduced access.[4] Why? The first study assumes that many people will share rides and continue to use metro systems. The second study assumes that people will shift away from public transit and towards SAVs, causing more congestion. Whether SAVs will result in more or less access depends upon how they are implemented and the public policies governing them.

[3] (Viegas and Martinez 2016).

[4] (Boesch et al. 2017).

Mode	Impact on Access	Populations of Concern
Working from Home	Increased access to employment	Blue-collar, hand-on workers
E-Commerce and Delivery	Increased access to goods for the time-constrained	People without internet access
Car-sharing	Increases access for those who do not own a vehicle	Non-driving populations
Smartphone Mobility Apps	Increased information about multiple modes for access	Persons who do not own or cannot use smartphones
Ride-hailing	Increase access for those who do not own a vehicle	Persons who do not own smartphones; unbanked
Micromobility	Increase access for short-distance trips in urban areas	Rural areas; persons with a mobility-limiting disability
Automated vehicles	Increase access for those who cannot drive	AVs raise costs, leaving out low-income populations
Shared automated vehicles	Increase access for those who do not own a vehicle	Persons who do not own smartphones; unbanked

Table 7.1: Access Impacts of New and Emerging Modes

7.2 *Equity of Future Technologies*

When discussing future technologies and the potential changes they will bring, it is crucial to think about a community's equity or social justice goals. Almost all of these innovations have the potential to increase inequality, and if they can be used to reduce it, that will only be as a result of conscious public policy forcing them to that end.

A typical new technology starts out expensive, which means that the wealthy try it first. As it scales, it becomes more broadly available, but there is likely to be a substantial percentage of the society that is excluded – for reasons of cost, or just because the technology isn't suited to them. The popularity of the new technologies among influential people can then encourage disinvestment in those services that lower income people – for whom the new technologies are least likely to be affordable – depend on for their access. This process can be observed in the rise of arguments that a combination of ride-hailing (short term) and AVs (long term) will somehow make public transport obsolete. Even if it were physically possible to meet everyone's access needs in a dense city by car, the effect of allowing public transit to wither would be increased inequality, measurable in the decline in access that lower-income people experience.

Telecommuting and e-commerce also have highly disparate impacts depending on income. Many lower-wage jobs cannot be done online, whether it's picking fruit, cleaning a building, making physical things in factories, washing dishes in restaurants, or filling e-commerce orders in warehouses. While many of these jobs may eventually be automated, so long as they remain filled by humans, they will require travel. Thus any access benefits from widespread telecommuting are likely to be very unevenly distributed. Any social changes that result – such as a hypothetical movement of permanent telecommuters out of cities, leaving only lower-income people behind – is likely to be especially harmful to those left behind.

As always, caring about equity means that we must measure the access of low-income or otherwise disadvantaged groups, and compare it to the access of the general population. If a proposed action worsens the difference between everyone's access and the disadvantaged group's access, the outcome can fairly be called inequitable. This will be more important than ever when considering these technological futures, because the potential for disparate impact is so large.

7.3 *Conclusions*

Across the world, access planners are implementing access policies and programs. This *Manual* has sought to provide a baseline of knowledge and resources on the issue of access. It explores use cases, measures, data, and tools to assist professionals and other interested parties who are facing these questions within transport and land use planning.

While planning tends to operate under the assumptions of a fixed level of technology being spatially deployed over time, we observe many prospective technological changes that will transform the design of cities in unpredictable ways. Telecommuting and e-commerce in particular raise questions about the future of cities, leading to significant decline in the importance of daily physical access, though it is impossible to imagine its abolition. To an economist, a metropolis is a job market, constrained by travel time.[5] Physical access to jobs, and physical commerce, are fundamental to why the city was invented, and why it persists.

[5] (Bertaud 2018: Chapter 2).

In short, new technologies have the potential to greatly increase access, but in general new technologies tend to favor those populations that already possess the highest levels of access – people wealthy enough to own a vehicle, who are physically capable of walking and driving, and with access to, and facility with, information technology. If new technologies are not to exacerbate already existing access gaps across the population, it will be important for transport planners and policy makers to consider which people have the greatest access needs, and how new mobility technologies can bridge the gaps and help meet those needs. Just as policy guidance without technological understanding is vacuous and misplaced, technology development without policy guidance cannot be expected to improve access across society.

One challenge now is how well-designed and interoperable the access tools are to allow their integration with more conventional tools used by land use planners, the larger strategic transport modeling systems used by transport practitioners, or the cost-benefit analysis tools used by budgeting professionals and transport economists.

Opening access tools to allow guidance on data formats used, preparation requirements, and documentation availability is fundamental. Indeed a critical aspect of access tools is that they would be used by a range of skilled practitioners: land use planners, transport planners, and government budget professionals, all of whom come from different backgrounds and speak different professional languages.

Planning for transport, land use, and their finance using access metrics offers the potential for a new dimension in collaboration, critical in this period of rapid technological shift in the transport and land use sector. And with its many dimensions, access has the potential to assemble practitioners, stakeholders, and final users. Thus, access tools have the significant potential to concentrate all of the key people involved in access planning around the same metaphorical table. In doing so, access must be used as a means to open discussion and not to limit it. In this sense, the future role of access depends on its ability to improve interaction. Recent studies[6] have highlighted a shift in the use of decision-making support tools from aids for *planning for people* to instruments for *planning with people*. In this sense, access tools are used both to communicate as well as to generate solutions to transport and land use problems. This new landscape requires access measures and tools that can support more interactive and participatory planning approaches.[7] .

[6] (Batty 2007).

[7] (Geertman and Stillwell 2003).

Appendices

A
Consequences

Access plays a major role in spatial analyses, and has been widely used in the scientific literature, especially in the economic and econometric literature, on which we base the following assessments. Access appears first as an important variable in most overall models, whether traffic models or spatial spatial modelling at metropolitan, regional, and international levels. Access also drives geographical mechanisms such as productivity, real estate prices, and many other ones. We will address those two fields, surveying the role of access first in general modelling, then in specific mechanisms.

A.1 Transport Modeling

In classic strategic transport models, the 4-step approach[1] develops along the following line:

[1] More recent agent-based or activity-based modeling approaches of course extend this trip-based approach, but the same basic questions need to be answered. Models in practice are more complex than this implies.

1. Trip Generation: Compute trips departing from (O_i) and/or ending in (D_j) each zone: given exogenous size characteristics — usually populations -– X_i and Y_j, or using estimates of O_i and D_j from former periods and evolution trends for X_i and Y_j

2. Destination Choice (Trip Distribution): Compute the flows of travel between zones i.e. T_{ij} where T_{ij} is the number of trips from i to j;

$$O_i = \sum_i T_{ij} \qquad D_j = \sum_j T_{ij} \tag{A.1}$$

3. Mode Choice: Estimate the choice of transport mode for these T_{ij} within a mode,

4. Route Choice (Route Assignment): Estimate the flows on links or services based on individuals behaving in user optimal way.[2]

[2] (Wardrop 1952).

Each of these sub-models has over recent decades been translated to rely on the framework of the workhorse discrete choice models. Following the classical presentations,[3] when a consumer is faced with several mutually exclusive options j (for instance going to destination A or B from the set of destinations J, or using mode 1 or 2 or 3 from the set of modes M). The consumer's indirect utilities are the sums of a certain component W_j[4] and a random component u_j, then the probability to choose option j is the probability that the utility of j, which is a random variable, is maximum. When the random parts u_j are independent and follow a Gumbel distribution with the same standard deviation, the formula providing the probability of j is especially simple:

[3] (McFadden 1986, Small and Rosen 1981).

[4] More precisely $W_j|i$, that is the utility of the destination (j) given an origin (i), but we drop the "$|i$" for clarity.

$$Pr(j) = \frac{e^{W_j}}{\sum_{j=1}^{J} e^{W_j}} \tag{A.2}$$

Applying this formula to the situation of choices between possible destinations (for instance employment opportunities or leisure resorts) located in areas j, assuming that all agents have the same utility function, and that job opportunities (or consumption opportunities) are independently and randomly located from a Gumbel distribution, it turns out,[5] that the traffic from area i to area

[5] (Cochrane 1975, Koenig 1974, McFadden 1986).

j is:

$$T_{ij} = O_i \cdot \frac{D_j \cdot e^{\beta \cdot C_{ij}}}{\sum_j D_j \cdot e^{\beta \cdot C_{ij}}} \tag{A.3}$$

Where:

T_{ij} is the travel flow from i to j.

O_i is the number of origins (e.g. workers or consumers) departing from zone i.

D_j is the number of destinations (e.g. jobs or shops) in zone j.[6]

C_{ij} is the travel cost from i to j.

Clearly, this formula uses a weighted cumulative opportunities access metric with a negative exponential weight (β): the numerator is an access index for zone j, and the denominator is the sum of access indices of all zones. Access is then an important variable in explaining the behaviour of transport users.

Even more, in the framework of welfare theory, it is also an indicator of the changes in welfare due to transport improvements.[7] The corresponding surplus (under the assumption that utility is separable and is also the sum of compensated variations) for people located in i is, for any change from state 1 to state 2 (for instance changes in C_{ij}):

$$S = O_i \cdot \frac{1}{\lambda} \log \left[\sum_j D_j \cdot e^{\beta \cdot C_{ij}} \right] \Bigg|_1^2 \tag{A.4}$$

This *logsum* formula can be derived more heuristically from the gravity equation which states that traffic between two nodes depends on the 'masses' of each pole and on the difficulty of traveling between them:

$$T_{ij} = k_i \cdot O_i \cdot D_j \cdot f(C_{ij}) \tag{A.5}$$

where:

O_i and D_j are the 'masses'.

C_{ij} is the transport cost.

f is the impedance, a decreasing function is called the impedance, typically an exponential or a power function.[8]

k is a coefficient such that the sum of T_{ij} over j is equal to O_i.

[6] Note, confusingly, the O and D here are reversed from how they are used in typical access calculations described earlier in the *Manual*, where O_j indicates opportunities at the destination, such as jobs, and in the competitive accessibility example in subsection 3.1.3 D_i indicates Demand for jobs (workers).

[7] This formula, whose right hand side is an access indicator, has been derived by (Small and Rosen 1981).

[8] See subsection 3.1.2.

k is then:

$$k_i = \sum_j D_j \cdot f\left(C_{ij}\right) \tag{A.6}$$

The previous formula corresponds to the so-called *singly constrained* model, where the number of trips generated from an origin is fixed, but where the number of trips arriving at a destination is not constrained. The *doubly-constrained* model, better adapted for home-to-work trips, states that both trips at origin and at destination are constrained. In such a framework, several authors[9] have shown that the traffic can be expressed as:

$$T_{ij} = O_i \cdot D_j \cdot A_i \cdot B_j \cdot e^{\beta \cdot C_{ij}} \tag{A.7}$$

Where O_i is the total number of trips coming from zone i[10] and D_j the total number of trips arriving in zone j,[11] and with the following relations defining A_i and B_j:

$$A_i = \left(\sum_k B_k \cdot D_k \cdot e^{\beta \cdot C_{ij}}\right)^{-1} \tag{A.8}$$

$$B_j = \left(\sum_r A_r \cdot O_r \cdot e^{\beta \cdot C_{ij}}\right)^{-1} \tag{A.9}$$

These interactions between the terms intervening in Equation A.7 of the access, can be named *augmented access*. Augmented access corresponds to a modeling framework where the interactions do not come from changes in masses at origins or destinations, but from the combined effect of changes in transport costs and some form of constraints on the flows and masses. These constraints are dictated by the nature of the modelled transport type; for instance for commuters, constraints play both on origins and on destinations. In the case of daily shopping, constraints play at origin, but not at destinations: the capacity of shops is, at least to some extent, flexible. These interactions make the changes of access due to changes in transport cost more difficult to reckon than in the plain gravity model corresponding to formula Equation A.5.[12]

Apart from the general confirmations of the impact of access on traffic implied by the use of this modelling framework, the effects of access on traffic variables have been directly confirmed by many itemized empirical studies, especially for commuting time.[13] and mode shares.[14]

[9] (Cochrane 1975) on an economic basis; (Wilson 1967) on a physics analogy basis.

[10] Referred to as *emission*.

[11] Referred to as *attraction*.

[12] But, strangely enough, this plain gravity model (level zero of interaction) is not supported by any simple theoretical model of utility maximizing behavior. See Cochrane (1975) who elaborates a model to that purpose.

[13] (Kawabata and Shen 2007, Levinson 1998, Vandersmissen et al. 2003, Wang 2000).

[14] (Kockelman 1997, Moniruzzaman and Páez 2012, Owen and Levinson 2015).

A.2 Economic Geography Modeling

Economic geography modelling has not reached the maturity of transport modelling. Its most common expression is through LUTI (Land Use Transport Integration) and SGEM (Spatial General Equilibrium Models), on which there is a large literature.[15]

[15] See for instance (Iacono et al. 2008, Wegener 2011) or (Bröcker and Mercenier 2011), while the use of models is developed in (Vickerman 2007).

The general structure of these model follows: the study area is split into zones, and the spatial distribution of activities (residential, industrial, commercial, health, education, administration, green spaces, etc.) -— described with a different level of detail according to the model -— and the transport costs generates displacement flows on transport networks that connect these different places. The form and the supply of transport systems (networks and their exploitation) determine the conditions of access to potential destinations from any possible origin within the territory. Changes in access result from changes in transport costs, then changes in flows and ultimately in locations of activities.[16]

[16] See section 1.2.

All these models include the consequences of transport on the location of activities. The mechanism of land rent relies either on an explicit economic auction mechanism, or on a heuristic representation through an access index; in this last procedure, the location of agents is a function of the access from which they will benefit; spatial distributions of access to and towards one or many locations influence planning choices of ground occupation, and thus, the settlement of households and firms (their headquarters and their different branches). However, this important factor of location is endogenous itself —- an improvement in access creates a modification of locations, which in turn modifies the factor that is its cause. For instance, improvement in the *absolute access* of an agglomeration can be accompanied by a loss in influence of this agglomeration (a loss of *relative access*) if it is accompanied by an even stronger improvement for other cities and changes of locations in their favour.[17])

[17] (?? bro).

These models include many other interesting features implying also access. Many models include market power (through monopolistic competition, such as CGEurope.[18] The CGEurope model predicts the spatial distribution of production factors without migration. Household and domestic sectors consume transport services in their consumption and production activities.

[18] (Bröcker 2002).

Agglomeration externalities in the MUSSA model[19] use the presence in the agent's utility function of a parameter that represents the advantages of the location. This parameter depends on the access of the place and its characteristics (e.g. neighborhood).

[19] (Martínez and Araya 2000, Martínez and Donoso 2004).

Cost-benefit analysis can also use this kind of model,[20] for instance where the density of the zone in which the consumers live represents the externality in their utility function.

[20] (Börjesson et al. 2014).

Some models also integrate labor market imperfections, especially in terms of reservation wage and search, which depend on transport.[21] This can be expanded to international trade and inter-regional migration in the field of trade, for instance, to assess the effect of EU enlargement.[22]

[21] Such as RAEM 2 (Koopmans and Oosterhaven 2011).

[22] (Gil et al. 2008).

In all these cases, access indicators play a major role. These indicators have different names and slightly different definitions according to the authors and their objectives: access, connectivity, or market potential.[23]

[23] Starting from (Hansen 1959), this category of indicators has been the basis of many publications, including (Alstadt et al. 2012, Geurs et al. 2010;?).

Access indicators can help an overall judgment on evolution through time or comparisons between countries.[24] On the theoretical side, the concept of access has been fine-tuned to address border issues,[25] and by the distinction between real market potential or nominal market potential.[26] or by the distinction of the access -— either from the point of view of consumers, or from the point of view of producers.[27] A good connectivity index (to represent the "pull" that a country or a node exert on other nodes) must fulfill several requirements, and for air transport it has been verified to be highly correlated with a number of economic measures.[28]

[24] (De Benedictis and Tajoli 2011).

[25] (Anderson and Van Wincoop 2003).

[26] (Head and Mayer 2004).

[27] (Redding 2010).

[28] (Arvis and Shepherd 2011).

A.3 Location of Activities and Investments

Unfortunately, we do not know much on migrations. Economic geography modeling assumes that there is no international migration and that inter-regional migrations are much smaller in Europe than in the US. On top of that, migrations are a dynamic process, taking time as shown by several studies.

Though, a lot of theoretical work has been done on the consequences of access on firm location in a framework of imperfect competition, based on theoretical situations of two or more firms located in a given space (in theoretical analyses, the space is either linear or circular) and analyzing the effects of transport costs on the locations of firms and on the competition between them. Those theories developed showing that firms' locations are under the influence of two contradictory forces:

1. The will to be where the consumers are; and

2. The desire to escape competition from other firms.[29]

[29] (Hotelling 1990).

Decreasing transport costs increase competition and induce firms to relocate farther away if possible.[30]

[30] (Thisse 1988).

Railway systems develop exchanges and increase revenues through increased accessibilities.[31] Using the framework of a Ricardian model, the proximity to a road has a positive but quite weak effect on revenue, and no effect on growth in China.[32] This result is explained by the weak capital mobility between the centers and the periphery. On the one hand, this point can be considered as disturbing, since hesitations lie on the theoretical background of the relations; but on the other hand, it is comforting regarding the interest of MP as an explanatory driver.

[31] (Costinot and Donaldson 2012, Donaldson 2018).

[32] (Banerjee et al. 2012).

The previous studies exemplify relations (essentially, wage related to Market Potential) that are drawn from a general equilibrium model. Other studies are limited to a single relation without being embedded in general equilibrium. The latter do not detail the trade costs, and more frequently use transport costs or infrastructure endowment of the zone under study. Using an Instrumented Variables (IV) methodology a 10% increase in a city's initial stock of highways causes about a 1.5% increase in its employment over a 20-year period.[33] Access from the US Interstate Highway System has increased decentralization of employment and residences at a similar pace.[34] In the Netherlands access through rail has had a major impact on the location of population, especially at the end of the 19th Century and the beginning of the 20th.[35] US data show that the causality between access and location plays both directions, and confirm that it is difficult to assess whether the effect is fully additive or just a transfer.[36]

[33] (Duranton and Turner 2012; 2018).

[34] (Baum-Snow 2010).

[35] (Koopmans et al. 2012).

[36] (Jiwattanakulpaisarn et al. 2010).

Over a longer time span, the changes have occurred in the rail network and density of population in London during the 19th and 20th centuries. Disentangling the 'chicken and egg' problem of which came first, network or land development, it has been shown there is a positive feedback effect between population density and network density.[37] Additional rail stations (either Underground or surface) are positive factors leading to subsequent increases in population in the suburbs of London, while additional population density is a factor in subsequently deploying more rail, with differences in central London and elsewhere, and with surface rail stations and Underground stations, Interestingly, an historical analysis of the decisions on the London Underground since its creation in 1863 shows[38] that among additional links proposed to the UK Parliament for approval, final decisions were largely explained by maximizing access to population (which was highly correlated with revenue and ridership).

[37] (Levinson 2007).

[38] (Levinson et al. 2015).

A.4 Real Estate Prices

Workers' residential location choice is not based on access alone. Among other factors, the choice is a trade-off between the access, and the affordability of the residential property. Access generally increases the value of land, and the price of residential properties. Proximity to urban centers, and the option value of having transit services generally raises the residential property value, and increases the development density. Immediate proximity to transport infrastructures will likely reduce the property value premium from access, due to noise and other disutilities [39]. Demand for residential properties with good access bids up the price, and thus the housing affordability is intrinsically an access problem.

[39] (Debrezion et al. 2007).

A general result is that access increases the value of land, and the price of residential properties. Many studies and references show the structure of transportation networks and the patterns of access as determinant of land prices, and hence urban spatial structure. While there is ample evidence on the cross-sectional relationship between location and land value (usually measured from the value of improved property), there is much less evidence available on the changes in this relationship over time, especially where location is represented using a disaggregate measure of urban access. Evidence of this dynamic relationship using data on home sales in the Minneapolis - St Paul metropolitan area, coupled with disaggregate measures of urban access for multiple modes, for the period from 2000 to 2005 yields empirical estimates which indicate that while most of the models estimated using a cross-sectional specification generate positive and significant effects of access on sale prices, these effects disappear when the models are transformed into first-difference form.[40] These findings are explained in light of the state of maturity of urban transportation networks.

[40] (Iacono and Levinson 2017).

In the majority of hedonic price studies, estimation results have revealed that housing values increase as access improves, although the magnitude of estimates has varied across studies. Adequately estimating the relationship between transport access and housing values is challenging due to several endogeneity issues (especially the clustering in space and spatial dependence, instead of being randomly distributed). A spatial lag hedonic price model in the Seoul metropolitan region, which includes a measure of local access as well as systemwide access, in addition to other model covariates suggests that the spatial interactions of apartment sales prices occur across and within traffic analysis zones, and the sales prices for apartment communities fall as access deteriorates.[41] Distance to the central business district remains a significant determinant of sales price in most studies.

[41] (Shin et al. 2007).

Hedonic models for the Dallas-Fort Worth region have been used to assess the importance of access on property valuations through logsum measures of access with various controls for quality attributes and household demographics.[42] Job access (a proxy for work and other opportunities) was estimated to positively impact residential land values. In comparison, access to park space (a proxy for availability of outdoor recreational activities) and access to retail jobs (a proxy for shopping opportunities) were not valued in the land market. Distances to regional CBDs and household heads' workplace locations also played important roles in location predictions, often in the presence of the more general access measures.

[42] (Srour et al. 2002).

A meta-analysis of the literature on railways stations on real estate values is mixed in its finding in respect to the impact magnitude and direction, ranging from a negative to an insignificant or a positive impact.[43] Studies of prices in French cities also emphasize the role of distance from the center.[44]

[43] (Debrezion et al. 2007).

[44] (Combes et al. 2019).

A.4.1 Market Potential

We have seen that the general models combine several elementary mechanisms implying access, and as such, provide information on these elementary mechanisms. But most of them have been studied in specific studies, dedicated to just one of the elementary mechanisms and not as parts of overall models. Those specific studies are in a sense partial as they do not take into consideration the interactions between mechanisms but they provide a better and more accurate information on each of them. We will now analyse with this view some of the most important mechanisms of transport and economic geography.

They are mainly based on the concept of Market Potential -— already seen in the basic formula of the gravity model -— derived from Armington (1969) and Anderson and Van Wincoop (2004) as previously quoted. Following Head and Mayer (2014). it can be written as:

$$X_{ij} = \frac{X_j}{\Omega_j} \cdot \frac{X_i}{\Phi_i} \cdot \phi_{ij} \tag{A.10}$$

$$\Phi_1 = \sum_i \frac{\phi_i \cdot X_i}{\Omega} \tag{A.11}$$

$$\Omega_i = \sum_j \frac{\phi_{ij} \cdot X_i}{\Phi_j} \tag{A.12}$$

where:

X_{ij} is the flow between i and j.

i is the exporting zone and j the importing zone.

Φ_j is the price index of zone j.

Ω_i is the market potential of zone i, related to the marketing possibilities of this zone, taking into account both the size of the other zones, the impediments to reach them, and the level of competition inside these zones.

It is easy to check how these formulae are akin to the formulae leading to single and double constrained gravity models already seen in the previous section.

Models derived from the New Economic Geography (NEG) give to Market Potential (MP) a crucial role in framing the equilibrium: Redding (2010) reviews empirical studies stemming from NEG on the effect of access on incomes. From an econometric point of view, these studies are marked by efforts to cope with endogeneity issues (e.g., when wages appear on both sides of the wage equation). Authors usually cope with it through Instrumented Variables (IV) methods.

These studies stress the importance of MP in wage setting in theoretical models -— nominal or real wage depending on whether population movements are possible or not. If population movements are possible—which is the case for regions of a country—real salaries end up being equalized. When population movements are excluded, the adjustment goes through wage changes. More precisely, several authors have studied this wage equation. Redding and Venables (2004) at the level of international trade and countries without mobility of workers, prove the effect of MP on GDP per capita. Puga (1999) has designed a theoretical model, including on top of the usual assumptions the existence of intermediate industrial goods where the mobility assumption is reduced to the possibility of workers moving from agricultural to industrial sectors, and shows the importance of MP and migrations on wage equalization. In this model, the bell-shaped curve can be derived from the effect of intermediate goods and movements of workers to and from agriculture and industry.

Building on this model, Brakman et al. (2006) find a clear relation between wages and MP at the level of regions in the EU, and the fact that agglomeration forces are more relevant at lower geographical scales. Hanson (2005) studied the differences in wages among US counties—linked them first to a simple access index, then to MP -— and found that the latter improved the explanation. Head and Mayer (2004) -— working also at the EU regional level -— show how wages and employment respond to changes in MP, and also measure the impact of human capital on wages. Head and Mayer (2014) find similar results.

A.5 Spatial Mechanisms

This section explains specific spatial mechanisms in which access plays a major role. Scientific and econometric literature has mainly studied the agglomeration effects, wage formation, location of activities, real estate prices, employment, and effects on GDP. Of course, such mechanisms intervene in several of the above presented general models. But these mechanisms were embedded in overall modeling, along with other mechanisms. And the models were not estimated through sound econometric methods, more often their parameters were calibrated through expert guess, or transferred from other sources. The quality of the model is not judged on the accuracy of each of the included mechanisms, but on the overall results in terms of economic activity, spatial dispersion, and so on.

In contradistinction, in studies on specific mechanisms, the parameters are more often derived from econometric methods, allowing calculation of significance levels. The issue is that, as it appears clearly from overall models, access is co-determined with the other variables, and is both a driver of the mechanism studied and an endogenous variable, rarely totally exogenous. This characteristic induces econometric difficulties to properly estimate the parameters of the relations.

We will first give a hint of these statistical difficulties and then present successively each of these items in which access intervenes.

Endogeneity Bias. Statistical difficulties stem from general equilibrium effects or endogeneity. Let us take for instance the case of the access to an industrial zone and its impact of the growth of activity in this zone. In the first round, the fact that, through for instance a reduction of transport costs, the access to this zone increases provides a benefit to the firms which are located there. In the second round, this increase in access will induce more firms to locate there, with two non exclusive possible consequences: first, as the zone gains in access (through an increase of the *mass*), more firms will locate there; second as the traffic from and to this zone increases, there may happen a congestion effect, going in the reverse direction. And there may be a third round, and so on. The problem is that the final effect can be quite different from the initial one, and a difficulty of statistical analyses is whether they grasp the first round consequences or the final ones, or some intermediate situation. And the pure effect of increase of access, with all other factors kept constant, is difficult to ascertain.

Selection Bias. Another source of difficulty is section bias. For instance, in the previous situation, an increase of the access of the zone will induce better productivity of workers in this zone and attract new workers from other zones; but those who are attracted are probably those whose productivity is already good and the gain in productivity inside the zone is probably partly a selection effect and not the real effect of productivity improvement. If observation shows that increase access is accompanied with increased productivity, it may be just that more productive firms relocate, and the overall productivity of the country may not be increased.

We will not dwell into the means to cope with these effects which amounts to distinguishing correlation and causality.[45] We will just keep in mind that these means are imperfect and that the coefficients drawn from these studies are not accurately determined. With such caveats, it is remarkable to see how many mechanisms are influenced by access, even if the quantitative measure of these effects is often difficult. Among them, we choose the agglomeration effects, the consequences on wages, the level of employment, real estate prices, location of activities, and GDP. But we should not forget that many other consequences are linked to access, such as for instance pollution or distributive effects.[46]

[45] More general information is provided in (Duranton and Puga 2020), who give also a wide view on the consequences of access.

[46] For a broader view, see (Fujita and Thisse 2013).

A.6 Productivity: the Agglomeration Effect

The general idea underlying this field is that when activities are close, production is more efficient.[47] The idea has been highly developed since the breakthrough of New Economic Geography (NEG). Agglomeration economies have three sources:[48]

[47] (Marshall and Marshall 1920).

[48] (Duranton and Puga 2020).

1. LEARNING: Learning good practices and diffusion of innovations through communication facility.

2. MATCHING: When there are many agents, firms find employees who correspond to their precise needs, and workers on the job that suits them more easily.

3. SHARING: The possibility to share, and hence to make profitable refined specialisations.

Most evaluation methods do not enable the differentiation of the effects according to their three possible sources. The theoretical basis is not demanding: it is based on the firm's behaviour[49] in a context of cost minimization under perfect competition in the input market.

[49] (Combes and Gobillon 2015).

This proximity factor can be expressed in several ways: either the real density and the surface of the area, or the *effective density*,[50] which is defined by a form of access to which market potential can be linked; or a mix of density for the zone and market potential for the relations between this zone and the other ones.[51]

[50] (Graham 2007).

[51] There are many surveys (especially (Combes and Gobillon 2015, Graham and Melo 2009, Rosenthal and Strange 2004, Venables et al. 2014) some noticeable studies include (Alstadt et al. 2012, Combes et al. 2015, Combes and Gobillon 2015, Graham et al. 2009, Melo et al. 2017, Sanchis-Guarner et al. 2012).

General results exhibit very large dispersion, between 0.01 and 0.1 for the elasticity of productivity to density or to access variables. But the elasticities diminish once endogeneity and selection bias are taken into account. It appears that endogeneity bias is not that large, but that selection bias (the fact that more skilled workers are selected or auto-select to be in large agglomerations) is very important: taking it into account lowers the elasticity of productivity to agglomeration by around 1/3. Using panel data and controlling for individual characteristics, lowers the elasticity of productivity to access from about 4% to about 1 to 2% in the case of France. Estimates for other countries are varying according to the same pattern, but with different sizes: for the UK they seem on the average to be larger, as well as for North America and for developing countries.

Effects differ according to the sector of activity: they are larger for tertiary activities and services than for industry and for primary activities (they are negative for agriculture). Innovative sectors benefit from the proximity of research centers or universities (80% of the spill-over effects take place in a 100 to 200 km range). Effects on tertiary activities are mostly urbanisation effects while effects on secondary activities are mostly specialisation effects.

Effects are also decreasing with the separation: they almost vanish beyond 20 minutes for services; they vanish beyond 3 hours for manufacturing activities. When the driver is pure density, the elasticity to density depends on whether market potential to adjacent zones is included and decreases with this inclusion. The effects of neighborhood, though decreasing with distance, appear through many shapes.[52]

[52] (Rosenthal and Strange 2019).

In order to use these results, for instance in order to assess the effect of a transport investment on productivity, several issues must be addressed, to which the answer differs whether the driver of productivity is density of the zone or access to neighbor zones. If the driver is the density in the zone, no information is drawn from the elasticity of density: when transport cost or time change density does not change, and there is no agglomeration effect, except perhaps when in the long or medium run changes in transport costs or time induce change in location.

But the fact that density is a good driver of agglomeration effects should be questioned; no thought experiment could conclude that these agglomeration effects rely only on density: when a bridge is built between two agglomerations previously separated by a river, densities do not change (at least at the beginning) but it is difficult to think that agglomeration effects will not appear.

An obvious general equilibrium effect is that changes of access induce changes in locations, which induce a second change in access, insofar as 'masses' at each point change, and possibly other changes due to the changes of travel times in the case of congestion effects (in case of congestion effect, travel times on transport links depend on the flow of traffic they bear). At the end of the day, the access and productivity effects will not be those reckoned 'at the first round', without taking into account the general equilibrium effects. Are these general equilibrium effects important? We will get a view of this question through a related concept, the wage equation.

A.7 Wages

Another stream of studies relating transport infrastructures and access to wages and economic activity, is the so-called wage equation, which has been subject to a lot of statistical estimates in the line of the New Economic Geography (NEG).[53] It expresses wages in an area as a function of the area's market potential (MP), an avatar of access.[54]

[53] Among the numerous texts presenting this corpus, see, without exhaustivity, (Fujita and Thisse 2013, Ottaviano et al. 2002, Proost and Thisse 2015), as well as (Combes and Gobillon 2015, Head and Mayer 2004).

[54] This wage equation has as many formulations as there are specifications of the Dixit, Stiglitz, Krugman (DSK) model.

A.7.1 An Example of the Wage Equation

Let us illustrate the wage equation by one of its avatars, following from (Bosker et al. 2010) and (Puga 1999).

$$w_t = \left(\frac{\sigma\iota}{\sigma-1}\right)^{\mu-1} q_t^{\mu/(\mu-1)} \left(\frac{\iota}{\alpha(\sigma-1)} \sum_j e q_j^{\sigma-1} \tau_i^{1-\sigma}\right)^{1/(\sigma(1-\mu))} \quad \text{(A.13)}$$

Where:

e_j - income of region j,

w_i - sum of the wages,

L - laborers,

K - revenue from land, and

q_i - price index of zone i (given by a similar equation implying the same variables).

$$e_i = \gamma\left(w_i L_i + K_i r\left(w_i\right)\right) + \mu/(1-\mu) w_1 \zeta_i L_i \quad \text{(A.14)}$$

The terms σ, ι, μ, α are exogenous parameters. The variable ζ_j is related to wages by a simple relation (Puga 1999). The variables τ_{ij} are the iceberg costs caused by transport to inter-regional trade. The model is fully specified with these three sets of equations (one by node), whose solution gives the q_i, the w_i and the e_i from which it is possible to deduce the quantities produced and exchanged.

The formula giving w_j implies the expression:

$$\sum e_j q_i^{\sigma-1} \tau_{ij} \quad \text{(A.15)}$$

This is called the *Real Market Potential* for location i and is akin to the access formulae quoted above in the fields of transport and classical international trade, but clearly related to the "augmented access" family as the q_j depend on the τ_{ij}.

The same market potential variables are found in almost all other models of that vein. The main difference compared to the previous models used in trade is that here the "masses" are depending on the transport costs, as it appears clearly from the second equation giving the wages w_i. In the full model there is another source of change of the *mass* with the transport costs: the revenue of the land-owners, which depend on the share of labor devoted to agriculture.

There are clear similarities between the wage equation (WE) and the agglomeration effects (AE) developed in the above section: both aim at explaining how wage depends on the environment and proximity of economic masses. But there are also many differences.

First, as it is clear from the above formula, wages in the WE stream depends not only on the size of the nodes e_j and on the *iceberg* cost of transport and trade t_{ij}, as it is the case in AE, but also on the price index of the nodes where exports q_j take place, and on the price q_i of the exporting.

Second, while the mass variable in AE is employment and the driver the proximity of workers (either density or access), in WE, the mass effects are values of consumption and production, generally weighted by their prices in the framework of a multilateral resistance function, and the driver is the proximity of markets of goods and their competitiveness; in that respect, WE is more akin to the gravity model.

Third, while agglomeration effects (AE) are based on a very partial theoretical analysis (the fact that firms are minimizing the costs and that the inputs are provided through competitive markets), the wage equation (WE) is the result of a general equilibrium model which explains not only the wages w_i but also the prices q_i and the incomes e_i, as well as the other variables included in the model depending on its specification. In the previous relation, all variables appearing on the right hand side of the relation are endogenous: w_j, q_j, and e_j. This point raises of course strong econometric concerns to cope with this endogeneity issues.

AE mainly pertains to short range effects, such as within agglomeration or the vicinity of agglomeration (at the level of employment areas in many European countries), though some often rather ancient studies [55] who works at the NUTS3 level (department in France) deal with regional effects. On the contrary, WE relates to inter-regional and international relations; the general equilibrium framework has rarely been used at the level of agglomeration.[56] Nevertheless it is remarkable that, whatever the scale of the study (agglomeration, regional or international) the effect of distance or travel or trade cost obeys similar patterns, through power laws with exponent around 1.5. [57] [58]

Another point is the crucial role of migrations. If the assumption is made that migration between nodes is possible, then those migrations will tend to equalize real wages (net of local costs of land and congestion) over all nodes, and real wages will then be all equal, while nominal wages will differ from one location to another according to the price level in each location. This assumption is not

55 (Ciccone and Hall 1993).

56 For instance (Ahlfeldt 2011).

57 (Graham et al. 2009).

58 The relative stability of the spatial decay parameter has complex consequences on wages and prices, as transport costs appear twice in the WE (on wages and on prices), and the interplay of these two factors is not simple.

sensible for international trade, as international migrations are rather limited. It is also questionable for inter-regional studies as it would imply equalization of real wages along the regions, which is not the case.[59]

[59] (Head and Mayer 2014).

The wage equation results are not easy to use for decision making, as the WE is a part of a general equilibrium model, it contains several endogenous variables: not only wages but also prices and the masses of nodes are endogenous, due to possible migrations. What happens in the case of a change in transport cost? A shock in transport costs will have very different final impact depending on whether there are migrations or not. In the case of migrations, these migrations will take place until real wages equalize. Let us illustrate this issue by the following sequence:[60] Starting from an initial distribution of labor over regions and over sectors within each region, a change in transport costs induces movements of labor between sectors within each region until sector's wages are equal within each region. From this point, which is a common basis to all migrations assumptions, several cases can happen depending on whether there is inter-regional labor mobility:

[60] Adapted from (Puga 1999) and (Bosker et al. 2010).

- if not, we have a long run equilibrium;
- if yes, we have a kind of short term equilibrium, with inter-regional real wage inequality; in that case labor moves between regions in response to difference in real wages, going to regions with higher real wages, until real wages are equalized.

A.8 Employment Rates

Access impacts labor market, and consequently impacts the level of economic activity. This causality has been less studied than the macro-economic approach above mentioned.

The main link between them is derived from the theories of spatial mismatch: classically, the level of unemployment depends on the matching between job suppliers and job seekers;[61] and the efficiency of this matching depends on transportation and access: the better they are, the better the matching is, and the lower unemployment is. These theories of spatial mismatch have been developed in the framework of urban economics.[62]

Let us first highlight search effects and the corresponding decrease in search costs as transport costs decrease. Improvement of access reduces the search time, and thus has an effect on the job market, about 20-30% of the traditional gain of time effects.[63] The spell between two employments within a metro area are linked to access.[64] Job search costs should be taken into account when assessing transport projects in remote rural economies.[65]

[61] (Mortensen et al. 1999).

[62] For instance (Gobillon and Selod 2014).

[63] (Pilegaard and Fosgerau 2008).

[64] (Andersson et al. 2018).

[65] (Laird and Mackie 2014), contrary to (Pilegaard and Fosgerau 2008).

A.9 Effects on Gross Domestic Product

Access appears also in the econometric analyses linking, at the macro-level of countries, the endowment in infrastructure, which is a kind of access index, to the Gross Domestic Product (GDP). Many studies have been achieved in this line, and many surveys have been done.[66]

[66] See e.g. (Melo et al. 2017).

In the literature, elasticities relate percentage changes in GDP to percentage changes in various indices: sometimes they are related to general public investment, sometimes they are related to all transport modes, some are related to a specific mode, generally road; the size of the infrastructures is measured by the length of infrastructures, sometimes by the construction costs; consequently, the results cannot distinguish between two programs of equal size, while it is clear that their effect on GDP may differ depending on their definition; second it appears that the more recent the studies, the lower the elasticities. In any case, the results are widely spread, ranging from -0.14 to +0.25. Though it shows a clear impact of improvements of access on the general economic activity, it seems that this stream of research provides too widespread results to be useful to assess a specific program, except to support the idea that a program of transport infrastructure induce an increase of GDP, without being clearly able to tell how much.

B
Planning

Access is a well-established concept in planning and geography research. But it is not yet as widely used in planning practice as we think warranted. The *access planning approach* enriches the 'conventional' planning approach by integrating the way people move with the distribution of places and opportunities they want to reach. The access approach accounts for people's ability to reach needed places, events, services, social contacts, and opportunities. This includes, but is not limited to, people's capacity to travel to where these elements are located in space.

Extending the basic application which simply counts opportunities that can be reached from a point, we can consider, for example, opening hours of public and private services, the costs of using such transport, and the balance between supply and demand for the services. The characteristics of individuals are also important variables, for example their level of education and their willingness to travel to particular activities.

Combining all these (and other) components in a single analytical framework allows a precise assessment of access levels and devise ways to improve them. In terms of policy solutions, the access approach is therefore not just focused on facilitating travelling *per se*, but on creating the conditions necessary for people to reach what they need. This range of options to improve access can include facilitating mobility, but also implementing land use measures that increase proximity to needed opportunities or changes in timetabling of desired services, among many other non-mobility related possibilities.

B.1 Benefits of Access Planning

Access planning has led to the development of decision support tools that measure, model, and represent access levels. The potential benefits of these tools in applied planning practice are huge: they offer a data-rich, visually appealing lens through which to analyze highly detailed realities.[1] Like all planning support tools, access tools, when used as a part of a much richer toolkit, can talk with and be interconnected and inter-operable with other tools. In this way, access tools can play a powerful role in facilitating decision-making processes concerning policy, planning, and strategic investments to create more efficient, equitable, and sustainable communities. They can also contribute to reduce dependence on mobility to experience access.

[1] (Halden 2015).

B.2 *Audience for Access Metrics*

One of the primary considerations in the selection of an appropriate access measure is the intended audience, their familiarity with access concepts, and their concerns. In general, less technical and more straightforward measures are preferred to black boxes for less technically adept audiences.[2] For example, if the intended audience is a policy board whose primary expertise is outside of transport, cumulative opportunity[3] should be strongly considered. Weighted cumulative opportunities[4] measures may be appropriate for an audience with a background in transport, as these measures provide a balance of strong theoretical basis with only a moderate level of technical detail.

[2] (Boisjoly and El-Geneidy 2017, Geurs and Van Wee 2004).

[3] See subsection 3.1.1.

[4] See subsection 3.1.2.

B.3 *Reflective of Planning Goals*

Access measures should be selected that are most representative of the planning goals identified by the planning agency. For example, if the goal is to improve economic opportunity for low-income populations, then a competitive access measure[5] should be considered, since each job opportunity can only be filled by a single job seeker.[6]

If the goal is to shift travelers into public transit, a weighted cumulative opportunities measure might be more appropriate, since it accurately reflects the resistance of travelers to more lengthy travel times than a cumulative opportunities measure does. If the consideration is providing adequate service to a service area, distance to the nearest facility may be the most appropriate measure.[7] In any case, different measures may be more or less reflective of different planning goals.

[5] See subsection 3.1.3.

[6] (Merlin and Hu 2017b).

[7] See section 3.2.

B.4 Improving the Adoption of Access Tools

The use of access tools has many benefits and clearly can enrich the classic transport planning or spatial planning approach. Yet when access matters greatly to individuals, communities and companies, why don't decision makers use access tools in planning practice? This section will provide some insights into the barriers that block widespread use of access in planning practice and possible pathways to overcome them.

B.4.1 The Barriers to the Use of Access Tools in Planning Practice

The costs and the complexity of access tools: Access analyses need extensive datasets, as detailed in previous chapters.[8]

[8] See chapter 6.

Fragmented and mobility-oriented legal and administrative frameworks: The lack of integration among transport, land use, and budgeting authorities and agencies is a major barrier to mainstreaming access planning. Often there is no requirement for different organizations to collaborate closely on major decisions concerning transport, land use, social equity, and budgeting. If transport agencies focus more on vehicles than people, and if urban management professionals neglect the ways in which residential, commercial, and industrial land use policies may impact individuals' transport decisions, the urban areas managed are likely to become spatially fragmented. Transport professionals are then asked to facilitate physical connectivity amid urban areas that have developed without appropriate spatial integration concerns, with the result often mobility-based solutions being put into practice. This increases people´s dependence on extensive traveling to have access to the places, people, and opportunities they need.

A select group of cities and countries have adopted specific access metrics within their governance frameworks, and have started to create a learning feedback loop of how certain metrics work in practice. Yet many urban and transport planners and budgeting practitioners have yet to fully embrace the diversity of methods and access tools developed.

Mobility-oriented project appraisal tools: Transport appraisal remains focused on growing the transport economy, rather than taking into account wider economic and societal needs. Social issues are often considered as problems to mitigate rather than as challenges and opportunities. Access planning has been held back by the dominance of appraisal procedures fed by traditional transport models. A key problem for political decision makers is how different strategies to solve a given problem should be compared in terms of their relative merits and drawbacks. This is a key concern for decision makers for many reasons, not the least of which is because they can be held legally responsible for poor decisions.

Different intellectual traditions have proposed a number of alternative solutions for this question.

- THE PARTICIPATORY INTELLECTUAL TRADITION has suggested that the best way forward is to *empower citizens* so that they can understand the technicalities of the problem faced and choose their preferred solution according to their own logic, values, and goals. This is often cited as a non-expert and non-elitist approach to decision making.

- THE ENGINEERING TRADITION has proposed *multicriteria analysis*. Here, possible solutions are rated according to different criteria, which can be anything that is seen as relevant by those involved in the decision-making process – from increased financial returns to less toxic waste being released into the atmosphere. Each criterion is given a different relative importance and then the solution that rates the best according to the selected criteria is chosen. People involved in multicriteria analysis are typically a mix of technical experts, political leaders, and public and private representatives.

- THE ECONOMIC TRADITION typically relies on *cost-benefit analysis* (CBA).[9] This technique was developed by welfare economists and proposes that a team of experts should compute all benefits and costs of the considered solutions (including, in principle, external costs and external benefits) using standardized approaches, and these benefits and costs should be converted into financial gains and losses for society. A CBA's key output are three figures: total (financial) cost of a given solution, total (financial) benefit of the same solution, and the difference between the two. The project or policy with the highest overall gain (benefits minus costs) is considered the best according to the CBA appraisal. This is an expert-driven approach, with a strong technocratic rationality supporting it. The key advantage of the CBA approach is the standardization of procedures. All transport decisions can be performed using the same calculations and technical protocols as long as the guidelines to perform CBA

[9] Though, much of this in fact derives from Civil Engineers (Ekelund and Hébert 1999).

appraisals are strictly followed. The decision maker is therefore given higher peace of mind regarding choices made and has fewer grounds to be held accountable for undesired results.

In terms of access planning, the key concern with CBA is that access principles are not necessarily well-aligned with the principles of welfare economics at a fundamental, theoretical level. Welfare economics equates consumption to satisfaction of needs. If people pay more to acquire or do something, it is because the thing they seek corresponds to an important need.

Access as a benefit measure is at least partly capitalized in land value, and thus should be amenable to CBA approaches. However some of that land value is due to relative access – that is, land appreciation at one location due to an infrastructure project is in part a transfer of value from other areas of a metropolitan region. Thus it is less likely to be taken at face value as traditional travel time savings metrics (which are also in part transfers) that have the advantage of being the *status quo*.

There are strong implicit concerns about equity and vulnerable people´s lack of ability to access what they need. This is a different approach than assuming that people using and paying for a given thing is an expression of the value they give to it.

As such, the access logic poses a large number of complications for CBA that remain unresolved. As a result, and also because of the powerful position that econometric thinking enjoys in contemporary political thought, mobility and transport continue to be the key concepts used to perform CBA appraisals. This proves to be a problem when a project or policy that would be well rated according to an access logic is rated poorly when assessed according to a mobility-oriented appraisal tool. In sum, the widespread use of mobility-based CBA is a barrier for the implementation of access planning and its tools.

B.4.2 Establishing Pathways to Mainstream Access Planning: an Integrated Approach

This sub-section aims to give some suggestions on how to identify and undertake concrete actions that can make access planning the dominant logic in the future.

TO INCREASE THE ACCESS APPEAL IN ECONOMIC TERMS: One of the strong points of the mobility approach is that it is associated with a very clear financial logic, as stated in the previous section. Value of travel time savings is widely accepted in cost-benefit analysis. This logic is typically seen as very appealing to many stakeholders. The same needs to happen to access if this approach wants to succeed:

- showing how outcomes would be different in the context of access based planning versus mobility-based planning,
- making evident the financial gains resulting from it and who benefits from them, and
- proposing a reasonable way to convert access gains and losses into financial gains and losses. This will generally involve quantifying land value appreciation due to changes in access.[10] Practitioners need an equivalent of the 'saving time' indicator, an appealing way of selling access projects, dealing with influential people and politicians.[11]

[10] See appendix A.

[11] Many hedonic real estate pricing models include access indicators, but these tend to be bespoke rather than standardized across models and transferable. We hope as standardized access measures are more widely deployed, such pricing models will use those measures, and thus give more consistently interpretable results about the value of access.

To develop and diffuse open access software and data for access planning: dissemination of open access software and data can reduce the high costs of access tools. New databases, enhance computer processing, and then enriched understanding of travel behavior would make access analysis possible. The confluence of open data, data standardization, and mobile computing, sensing and communication technologies has driven numerous technical innovations for measuring, modelling and representing access at low prices. User communities of open access software could provide technical support, guidance, and updates, and help access pioneers to develop or apply access tools. The relative ease of access to new software and dataset means they have the potential to be a standard tool used by both professional planners and community groups.

To make access part of the common sense language: Access tools for daily and corporate use are already available and being widely adopted. Many real estate agencies, job searching platform, food delivery services, transit systems companies, and public facilities management organizations have launched their access-based tools. As a result, people are getting used to make a growing number of daily decisions based not just on mobility metrics but also on access metrics. These applications are paving the way to make access part of everyday language and usage.

Unfortunately, the term *access* is not necessarily very clear for many. *Accessibility*, for instance, is typically associated with the ability of disabled people to reach given venues and services. This is naturally a key aspect in the access planning field, but there is much more to it. It is therefore important to develop a well-articulated understanding about what the word *access* means. One element to mainstream the access approach is to promote a demand for access from the public. In other words, it is crucial the role of everyday apps and tools used by the people, to make them aware of the concept and the benefit of access, rather than the mobility ones.

This is what is already happening in a number of mobile phone apps and web sites. One example are the websites of real estate agencies that provide access maps with schools, health services and public transport stops reachable from the property they are trying to sell or rent. These indicators are, in fact, access indicators that inform the person not only about where a given venue is and how long it takes to get to it (mobility concerns), but also about whether the considered venue provides a service that will effectively satisfy the specific needs of each person (access concerns). What is missing is a linguistic device that shows to people that these are in fact access issues as framed according to the access approach, and that planning can be greatly benefited by this way of conceptualizing reality. This will make it easier for the wider public to understand the societal and individual benefits of the access approach over the mobility approach.

To IDENTIFY AND MOBILIZE IMPLEMENTATION NICHES AND FUNDING. When considering the implementation of access policies, it is fundamental to identify the right institutional, geographic, and community niches. Actors in some of these niches will have stronger motivations and will be much more open to the access logic than others. Access planning has much to offer to a wide variety of businesses and corporate interests and might represent for these actors something as desirable as acquiring more clients or finding better places to invest. It could also translate into employees spending less time stuck in traffic jams or demanding subsidized parking. Access-oriented niches might be hard to identify inside public organizations, which tend to be hierarchical. Nevertheless, there are sometimes units and agencies that have some authority to move in their own direction and might operate as niches for the development of access-oriented policies. Innovative and untapped streams willing to advance the access planning logic are wide and varied: supermarket chains and other companies with large numbers of visiting costumers; factories and other companies with large numbers of employees; local communities experiencing negative traffic externalities such as noise and pollution; community networks based on a common interest such as farmers´ markets or street closings for weekend recreation; and non-profits and NGOs focused on sustainability or the preservation of historic sites affected by excessive traffic. Though these entities might not be able to invest considerable sums in these initiatives (or none at all), they might have strong capacity to mobilize public support and media attention.

Funds and other forms of support for access-oriented developments should also be pursued via official procedures requesting support from budget managers, submit applications to funding agencies, or engage in some form of negotiation with influential political decision makers. Of course, this strategy follows very official lines along beaten tracks, and tends to require a lot of preparation.

To develop the understanding of access, how it is changing, and the societal consequences of such changes. The theoretical and practical understanding of access in place might be based on observations made in the past and on conceptual assumptions which are no longer valid. We are witnessing changes in certain types of travel behavior that have the potential to fundamentally change society. Among these one can mention the practice of work at home. In the meantime, online shopping is increasing while traditional retail tripmaking is falling. This has important consequences in terms of access measurement and planning. Awareness needs therefore to be raised about the fact that access metrics are premised on certain social structures and practices and these might cease to be as important as they used to be. At the same time, new trends might emerge to confound both the analyst and the decision maker, particularly if these trends pass under the radar of access metrics. If access planning continues to be centered on problems that used to be important when planning was focused on mobility, a paradoxical situation might emerge in which a new (access-centered) paradigm appears to address trends that used to dominate but no longer do. There is consequently the need to keep access planning open to evolution. In the same way that in the past transport and mobility centered planning has been evolving towards access planning, in the future access planning might evolve to something else that we cannot fully understand or even envision yet. The best outcomes will probably emerge if the research and practice on access keeps itself alert to social mutations, curious, and self-critical.

C
Selection

Access measures[1] calculate the ease of reaching valuable destinations, opportunities or social contacts.[2] Access can be defined as an indicator of the potential for interaction of one place and persons to all other places or persons. Accordingly, access metrics combine:

[1] We use the terms *metrics* and *measures* interchangeably.

[2] (Hansen 1959).

1. Travel costs which represent transport network features,

2. Opportunities reflecting the land-use characteristics, and a number of other possible variables that describe the temporal constraints, needs, abilities, and opportunities of individuals.

In broader terms, access metrics merge the pursuits of transport and urban planners, financial experts, social workers, logistics professionals, among many others, in designing built environments where people reach and meet their needs.

Access metrics constitute the building blocks of particular decision support tools, which we refer to as *access tools*. Access tools can be defined as the geospatial applications based on access metrics that assist government, communities, businesses and individuals achieving two key goals.

First, they facilitate deeper insight into the extent to which a certain place, service, person or group of persons is reachable, and by whom, from where, and using which resources.

Second, and by means of taking into consideration the insights gathered, they aid decision-making processes that are concerned with access issues. These can be private decisions such as where should one buy a house to enjoy a satisfying level of access to local services, schools and health care; or they can be highly complex and collective decisions that involve a large number of people.

We focus on access tools for planning practice, meaning tools used by planning practitioners that are able to assess access performance.[3]

[3] (Litman 2008).

The ability that many of these tools have to visually depict data and alternative scenarios makes them useful to facilitate communication among stakeholders as diverse as political decision-makers, technical experts, and community and business representatives.

Transport agencies, local authorities, and planners need to decide where to invest and how to improve their transport networks to improve access to employment opportunities and services. They also need to ensure that networks are affordable and safe for lower-income residents. Another key problem is to decide where to locate new developments, to seek opportunities for densification supported by the transport network. The use of access metrics and access tools in planning practice (or what we will refer to as 'access planning') can facilitate these decisions.

Access planning is a comprehensive approach to strategic thinking in integrated land use and transport planning[4] and it aims at developing integrated transport and land use strategies that locate and remove barriers to constructive and sustainable interaction, especially for individuals and institutions most at risk of exclusion from important social and economic dynamics. Access planning has been indeed developed with the goal of delivering broader societal goals relating to economic growth, social integration, and sustainable development. Access indicators are fundamental to studying geographic patterns of deprivation and exclusion, in particular when combined with information that shows the location of pockets of low income or high unemployment.

[4] (Venter 2016).

The benefit of using access tools for planning can influence investment decisions and policy outcomes to expand access to opportunity. Accordingly, several factors should encourage planning practitioners to develop and use access tools:

- Knowledge enhancement: practitioners have to face problems, dilemmas and uncertainties that derive from not knowing enough. To a large extent, access tools can help practitioners acquire further knowledge to deal with their daily challenges.

- System thinking: access tools have the potential to bring sectors together to agree upon shared actions programs. Access tools display the interconnections between assorted planning problems (e.g. transport planning, land use planning, economic development, health care, education, and food security), population groups, and geographic areas.

- INTERACTION OF DIVERSE STAKEHOLDERS AND FACILITATION OF DIALOGUE: access tools help gathering diverse stakeholders to work together towards common goals and to create a shared language for discussing community conditions and priorities.

- COMMUNICATION WITH THE PUBLIC, CLIENTS OR INFLUENTIAL DECISION MAKERS: access tools offer a positive framework for action on specific shared agendas among transport authorities, transport users, destination providers or landowners.

- SOCIAL EXCLUSION AND INEQUALITY: access tools depict access disparities and can be used to quantitatively demonstrate the impact of these disparities on the community.

- EVOLUTION OF POLICY, PLANNING, AND INVESTMENTS (IN TRANSPORT, LAND USE, AND RELATED FISCAL FIELDS): access tools facilitate decision-making by highlighting priority investments concerning social policies, and by providing insights into how to expand access to opportunities through changes in planning and policy.

- DEMOCRATIZED DATA ACCESS: by presenting data visually, access tools make high-quality information available in a clear format to a wide range of users.

- SUPPORT OF DIVERSE ORGANIZATIONS: access planning can support advocacy organizations with campaigns; non-profits with fundraising and program design; businesses and service providers with location decisions; governments with policy, planning, and budget decisions; and foundations with setting priorities.

- EMPOWERED COMMUNITIES: by helping communities shine a spotlight on the challenges they face and providing data to help inform potential solutions, access tools support community-driven policy change.

Nevertheless in practice there are still some barriers in using access metrics and tools. Transport planners typically focus on the transport component of access, using transport demand models and distinguishing between various time and cost impedance factors, but ignoring the land-use and individual components of access.

Urban planners and geographers typically focus on the land use component and less on the transport component of access. Furthermore, there is often a lack of attention for the interactions between the different components of access. Moving forward, transport and urban planners at all levels of government would benefit from using access tools within their current techniques, decision-making frameworks, and communications with colleagues, superiors, private sector colleagues, and community partners. Access tools should be integrated with the tools commonly used by land use planners, transport practitioners, budgeting professionals and transport economists. Like all planning support tools, access tools should be used as a part of a much richer toolkit, and it is crucial that access tools can talk with and be interconnected and inter-operable with other tools.

This review lays the groundwork for selecting access measures for transport analysis.

C.1 Components

Access is a highly flexible concept, which creates both opportunities and challenges around reporting clear measurements. Many different definitions of access metrics have been developed. We categorize access into four main components:[5]

[5] Following (Geurs and Van Wee 2004).

1. THE LAND USE COMPONENT reflects the amount, quality and spatial distribution of activities in space (houses, jobs, shops, health, social and recreational facilities, etc.);

2. THE TRANSPORT COMPONENT describes the transport system, expressed as the dis-utility for an individual to travel between two places using a transport mode; the dis-utility includes the amount of time, the costs and effort of travelling. The weighted sum of these components is named generalized travel cost;

3. THE TEMPORAL COMPONENT considers the temporal constraints of individuals such as the availability of opportunities at different times of the day, the time available for individuals to participate in specific activities;

4. THE INDIVIDUAL COMPONENT incorporates the needs (depending on age, income, educational level, household situation, etc.), abilities (depending on people's physical condition, availability of travel modes, etc.) and opportunities (depending on people's income, travel budget, educational level, etc.) of individuals.

These components interact in multiple ways and changes of one component, for example, the land use one might induce changes in the transport system component and vice versa. A major challenge is to create and use a comprehensive access metric that treats the four components of access. On the other hand, these types of metric are very complicated and hard to apply in practice.

C.2 *Classification and Assessment*

There are many different possible categorizations of access metrics. We distinguish four perspectives and relative clusters of access metrics.[6]

[6] Following (Geurs and Van Wee 2004).

C.2.1 *Infrastructure-based Metrics*

This perspective is a typical domain of transport analysts. These range from simple travel speed and congestion indexes to more complex network-based metrics analyzing the performance of an area in the transport network, based on graph theory. These indicators describe access using the transport system attributes, without considering the attractiveness of destinations. Those are:

- TOPOLOGIC METRICS that measure the transport network characteristics and quantify the time-space separation between pairs of points of the network. Within this group belongs the distance and travel times.

- NETWORK-BASED METRICS are founded on graph theory measure the properties of transport networks; according to them, access is directly related to the concept of the network centrality of a node.[7]

[7] Different metrics of network-based access have been defined including degree, closeness, betweenness, straightness and information. Examples of this metric are the indicators used by the SNAMUTS tool, described in subsection D.1.3.

C.2.2 *Location-based Metrics*

Location-based metrics can be used from the perspective of the origin of the trip, such as the location of the dwelling of a person (measuring the potential to reach a number of facilities) or from the perspective of the destination of a trip, such a location of a shop (measuring the potential number of clients). There are many different operationalizations used in the literature. The two most popular are:

- CUMULATIVE OPPORTUNITIES METRICS calculate access as the number of opportunities that can be accessed within a given distance or travel time or generalized travel cost, from the perspective of a single place. The cumulative access metric is a simple indicator expressing the absolute number of opportunities within a specified travel cost.[8]

[8] See subsection 3.1.1.

- WEIGHTED CUMULATIVE OPPORTUNITIES METRICS[9] depends on the number of opportunities that can be reached and by the cost

[9] These are sometimes called *potential* or *gravity* metrics.

to reach the opportunity. These metrics multiply an 'attractiveness factor' measuring the total number of opportunities located in an area and an 'impedance function' representing the distance, time or costs between to reach that area. In more complex cases, the weights are powered by an exponent greater than one to take into account the agglomeration effects (if any), whereas the impedance function typically includes the travel time in a negative exponential form, based on the assumptions that: the attraction of a destination increases with size and declines with travel cost.[10]

[10] See subsection 3.1.2.

Cumulative and weighted cumulative opportunities metrics implicitly assume that the demand for available opportunities are uniformly distributed in space, and do also not account for capacity limitations of available opportunities. They can be extended with competitive access measures.[11]

[11] See subsection 3.1.3.

C.2.3 *Utility-based Metrics*

UTILITY-BASED METRICS are founded on the assumption that individuals aim to maximize the net utility of participating in activities located in an area. Several utility-based metrics of access have been developed, depending on the modeling framework used. Probably the most well-known metric is the logsum metric derived from the multinomial logit model.[12] The main advantage of this access metric is that it can be converted directly into monetary terms, taking account of the dis-utility of travel time and costs. Utility can also vary for different individuals or places.

[12] See Equation A.4.

C.2.4 *Person-based metrics*

PERSON-BASED METRICS analyze access at the level of the individual level, e.g. 'the activities in which an individual can participate at a given time'. This type of metric is founded in the space-time geography. These metric take into account the daily activity schedule and the related trip chain as well as the spatial and temporal constraints of each activity. They contribute to extent the definition of access by incorporating concepts such as trip chaining, daily schedule and duration of the activities undertaken. Person-based metrics recognize that activity participation has both spatial and temporal dimensions, that is, activities occur at specific locations for finite temporal durations.

C.3 Selection of Measures

The selection of the access indicators, input data, local human capital and skills, and specific software, as well as the resulting performance of the tool, involve a series of interconnected steps, which are strictly related to the identification of potential data sources and the budget available.

Access tools differ significantly concerning performance and usability. Some fundamental aspects are the quality of data, the quality of calculations, accuracy of the results, visual representation, understandable output, transparency (how easy is it to understand the assumptions), flexibility (the ability to adjust the instrument during application), accuracy of the model, speed, ease of use, skills and resources required, and interactivity (the ability to interact with the instrument).[13]

[13] On the usability of access tools, see (te Brömmelstroet et al. 2014) and (te Brömmelstroet et al. 2016).

All these performance features again directly relate to the access indicator embedded in the tool. From the sample of tools analyzed, there is an apparent prevalence of tools using cumulative opportunities metrics, the metric that can be much more easily communicated and understood. This type of metric can reach another level of complexity and data quality and quantity, and it shows a quite good correlation with the weighted cumulative opportunities metric, as demonstrated in the academic literature.[14]

[14] (El-Geneidy et al. 2016) and (El-Geneidy et al. 2011).

The main disadvantage of more complex tools is that they are harder to use.[15] A major methodological challenge for tool developers is to find the right balance between scientific rigour and usefulness for practitioners.

[15] (Geurs et al. 2015).

Infrastructure-based metrics are easy to interpret and to communicate to planners and decision-makers. The spatial, temporal, and individual components are not directly incorporated in the metric, but the analysis can be stratified across many dimensions.

In contrast, more complex metrics such as utility-based or person-based data have the advantage of including individuals' characteristics. Indeed, access tools that make use of the potential access metrics necessitate much higher skills and resources (both in terms of time and money to build them).[16] The data and computational overhead required with these and many other models can be a barrier to adoption by non-specialist decision makers,[17] reduce their utility for rapidly exploring a wide range of options and policies, and limit the feasibility of their incorporation into a broader assessment of non-transport urban sustainability issues.

[16] For instance, for long-range planning, forecasts of the individual characteristics are required, or strong assumptions need to be made, otherwise the measure devolves into a weighted cumulative opportunities measure.

[17] (te Brömmelstroet et al. 2014).

Furthermore, the simpler the access metric, the less time is needed for the calculation. The time for applying the instrument depends on the type of tool used. Indeed, all of the tools that use cumulative opportunities metrics are supported by interactive and real-time online platforms. This is not the case for access tools using utility-based metrics, which need time to run the calculations.

Access tools should effectively convey information using clear, easy-to-understand communication vehicles that support specific policy goals. One of the critical aspect of an access tool is indeed the communication power of the access metrics. The quality and usefulness of communication capabilities are key elements that define access tools. As stated earlier, access tools should be a means to communicate with a broad range of stakeholders, including communities, clients, and relevant decision makers with different backgrounds. But how does a tool communicate effectively with everyone involved?

To reach this goal, it is essential to understand as much as possible the stakeholders involved. In most of the analyzed cases, communication tools to support access planning practice are in the form of objective expert-produced maps. In other cases, the output of access tools can be in written form or numerical, listed in tables, matrices, or datasheets, without offering any visual mode. Planners and transport practitioners can easily read maps, but financial professionals, decision-makers, and those suffering ingraphicacy might still prefer text. Communicating with large communities may be facilitated by the use of storytelling or more effective written synthesis.

All access tools analyzed here use maps as the main communication tool, and the visual communication constitutes the principal means of interaction with the stakeholders involved. The maps that the tools are able to produce differ in terms of the quality of information presented, the level of interaction, the mapping format, graphic design, clearness, effectiveness, and accuracy. For example, simple cumulative opportunities maps can facilitate dialogue with non-experts. Graphical capabilities are improving dramatically, offering new ways to communicate directly with citizens and policymakers—a crucial component to driving policy change. Tools that are part of an interactive web-based display of a proposed transport network and schedule have much more chance to be used by final users and planning practitioners. The advantage is indeed that final users and planning practitioners use the same tools in an open and transparent process.

In some cases, analyzed access tool websites[18] provide an

[18] See appendix D.

	Infrastructure-based	Location-based	Utility-based	Person-based
Theoretical basis	-	+	+	+
Data requirements and costs	-	+	+	+
Interpretation / communication	+	+	-	-
Usability in economic appraisal	-	+	+	-
Usability in social evaluations	-	+	-	+

Table C.1: Assessment of Access Measures

overarching communications platform for the access maps and the project as a whole. The sites can be used to set forth a conceptual framework for the project, share analysis of the access maps and data, offer policy recommendations, and provide background information. GIS packages can also be used to share additional information relevant to the project, such as supplemental data, white papers, stories, and how-to information.

The outputs of access analysis strongly depend on the access metric chosen and its implementation. It's then crucial to select the metric or the combinations of metrics to use.

Criteria that might help the selection process include: the theoretical basis, the ease of implementation, interpretability and communicability and usability in social and economic evaluations.[19] In Table C.1 we compare the classified access tools according to these criteria.

[19] Following the criteria of (Geurs and Van Wee 2004).

The decision about how many access indicators to include should be a strategic one guided by the specific purpose. However, given the cost of acquiring, preparing, and maintaining each indicator, strategic considerations will need to be balanced with financial and practical ones. Based on the Committee's assessment in Table C.1 at the time of this writing, we selected the location-based family of measures as most appropriate for development and description in this *Manual* and use in practice for places and organisations which are new to access analysis. These include opportunity-denominated primal cumulative opportunities, weighted cumulative opportunities, and competitive access measures, as well as time- or cost-denominated dual access measures.

D
Tools

This appendix catalogues and compares various tools that have been deployed in practice, as of c. 2020, to communicate and calculate transport access. It reviews access decision-support tools and addresses remaining barriers to use in professional practice. It supports potential users of access tools —- principally land use, transport, and budgetary professionals -— by providing examples of accounting more effectively for access in plans and projects. This appendix also suggests how access tools can help them to work more effectively and to communicate more constructively with decision makers. Guidance on managing the development and implementation of a custom access tool follows in Appendix F. [1]

[1] Additional examples and guidance are also available in (State Smart Transportation Initiative 2017).

Section D.1 describes and compares access and visualization portals that have been developed and applied around the globe. Tables comparing the key characteristics and features of each tool are provided, as well as links to key source documents. Section D.2 focuses on software for calculating access, with reflections on performance and usability.

D.1 Tools to Quantify and Visualize Access

Numerous tools have been developed to help quantify access. These tools range from simple spreadsheets to metrics that are estimated by Land Use Transport Interaction (LUTI) models.[2] This section reviews a selection of access tools applied in different contexts.

[2] See section A.2.

The initial selection criteria were developed with the intent to make the selected tools as representative of the universe of existing tools as possible, focusing exclusively on passenger-related tools.[3] The specific selection criteria were:

[3] Freight-centric access tools are also available, but have not been reviewed.

- Application in practice. All selected study cases have been tested and applied in planning practice. While this criterion excluded some innovative and experimental tools found in academic literature, it ensured this section includes only case studies that had a direct application for planning problems and be used in the immediate term.

- Diversity of contexts. This criterion has the aim of covering different approaches and tool structures, which are in some cases a direct consequence of the specific context in which the tool is developed. National regulatory frameworks or the cultural background of tool developers' vary across countries, and these differences have implications for tool design.

- Diversity of planning purposes. Access tools differ in terms of the planning goals they can help to achieve. Different planning goals influence tools' design, structure, data inputs, and software requirements. Therefore, we selected tools that could support planning professionals facing different challenges and objectives.

- Diversity of geographic scale. Directly related to the planning goals is the geographic scale to which tools are applied, whether to local, regional, national, supranational, or even global transport challenges. To cover these differences, tools were selected with different geographic scales, also if they had the same planning purpose.

- Diversity of management features. Not all tools require the same level of management inputs, including costs, licenses, or the skills required. This guide includes examples of tools that differ according to these specific features.

The following subsections are organized to discuss tools by audience, type of measure, context, and application. In line with the recommendations of this *Manual*, the greatest attention is paid to location-based measures for professional planners.

D.1.1 Audience: General Public

Before proceeding to professional audiences, it is worth noting that an increasing number of access tools are designed to inform the general public about the geographic distribution of access. These tools provide excellent communication bridges, learning opportunities, and feedback mechanisms among public organizations, private organizations, and individuals. With them, public authorities and private service providers can make available excellent and real-time information. Conversely, individuals will produce large amounts of data using the exact information requests they send and the settings they choose. Planning practitioners have therefore much to benefit from engaging with these tools, not only as end users, but also as developers.

Online mapping tools often have no capabilities for scenario analysis – the input variables are fixed. However, professionals sometimes use them in baseline analyses or to assess trends over time. Most of their use is for the general public; helping people making their choices to meet personal needs more effectively. Recognizing the benefits of these tools, a growing number of service providers have developed their online access platforms to help their clients choose the facilities and services they want to use from a given geographical point (perhaps their residence or workplace) within a time and or distance threshold defined by the client.

One example is the Service Search Tool by the UK National Health Service that lists and maps the location of health services within a straight-line catchment area from any place in the UK. The online tool also allows narrowing the search by changing buffer distances, user ratings, patient services and opening times.

Other typical applications of access tools for private users are the ones provided by real estate services. The apps help to determine the best neighborhood to which to move, taking into consideration criteria such as proximity to schools, medical care, and public transport. The Opportunity Score tool developed by RedFin Real Estate, for example, provides an address-level score from 0-100 that takes into account the number of jobs accessible by transit, along with the population of the surrounding area and the average cost of different house typologies.

Table D.1: Access Tools

Num.	Name of the Access Tool	Developer Nation	Measure Type	License
1	Access to Jobs and Workers Via Transit Tool	USA	cumulative	open access
2	Accessibility and connectivity statistics UK	UK	cumulative	ODbL
3	Accessibility Atlas Västra Götaland	Sweden	weighted cumulative	open access
4	Accessibility Calculator	Canada	buffer measure	open access
5	Accessibility Observatory	USA	cumulative	open access
6	Affordable Housing Founder	USA	cumulative	open access
7	All Transit	USA	cumulative	open access
8	BBSR Accessibility Instrument	Germany	weighted cumulative	open access
9	Bikeprint	The Netherlands	cumulative	open access
10	CoAXs Collaborative Access-based Stakeholder Engagement	USA	cumulative	open access
11	ERSI Business Analysis	USA	network based	closed source
12	GMAL Great Manchester Accessibility Levels	UK	weighted cumulative	ODbL
13	Great Schools	USA	cumulative	open access
14	Highway Access in Europe	Europe	cumulative	open access
15	ISOSCOPE	Germany	cumulative	open access
16	Job Accessibility Maps	USA	cumulative	open access
17	LUPTAI Land Use and Public Transport Accessibility Index	Australia	cumulative	open access
18	Location Affordability Index	USA	cumulative	open access
19	Location Opportunity Footprint	USA	cumulative	open access
20	Mapnificent	Germany	cumulative	open access
21	Mapumental	UK	cumulative	closed source
22	Matka-aikakartta	Finland	cumulative	open access
23	MetropAccess-Digiroad Tool	Finland	weighted cumulative	open access
24	MetropAccess-Reititin	Finland	weighted cumulative	open access
25	Metropolitan Chicago Accessibility Explorer	USA	cumulative	open access
26	Missed Opportunity: 100 Metropolitan Profiles	USA	cumulative	open access
27	Move Meter	The Netherlands	weighted cumulative	closed source
28	Multimodal Accessibility Analysis	USA	weighted cumulative	closed source
29	Nationale Bereikbaarheidskaart	The Netherlands	weighted cumulative	closed source
30	NYC Neighborhoods: Mobility and Economic Opportunity	USA	cumulative	open access
31	Opportunity Score	USA	cumulative	open access
32	OTP Analyst	USA	weighted cumulative	open access
33	Plan a Journet TFL	UK	network based	open access
34	PolicyMap Opportunity Tool	USA	cumulative	closed source
35	PTAL India	India	network based	open access
36	Regional Equity Atlas - Denver	USA	cumulative	open access
37	Regional Equity Atlas 2.0	USA	cumulative	open access
38	RPA Job Access Map	USA	cumulative	open access
39	Service Near You	UK	buffer measure	closed source
40	SNAMUTS Spatial Network Analysis for Multimodal Urban Transport Systems	Australia	network based	open access
41	CUBE Access	USA	cumulative	closed source
42	TIGRIS XL model	The Netherlands	weighted cumulative	closed source
43	TRACC	UK	cumulative	closed source
44	Transit Time NYC	USA	cumulative	open access
45	TUM Accessibility Atlas	Germany	weighted cumulative	open access
46	Urban Network Analysis Tool	USA	network based	open access
47	Urban Observatory	USA	cumulative	open access
48	ViaMichelen	UK	network based	closed source
49	WebCAT Web-based Connectivity Assessment Toolkit	UK	network based	ODbL

Other real estate platforms (e.g. Trulia) also provide multi-modal commute time and access metrics for homebuyers and renters.

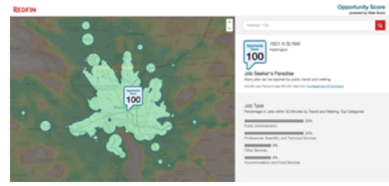


Figure D.1: The Opportunity Score, developed by Redfin Real Estate uses access metrics to help their clients to choose where to buy or rent a house.

LinkedIn has a feature in its job search app that measures commute times for prospective jobs. The feature allows users to filter job postings by preferred commuting mode, duration, and starting time.

Publicly-oriented access tools are in some cases developed by citizens, with the support of the government. This is the case of the Opportunity Project, started in early 2016 by the White House, the US Census Bureau, and the US Department of Housing and Urban Development, facilitating a process in which tech developers work with subject matter experts and cities to build digital tools that help families, community leaders, local officials, and the media access what they need.

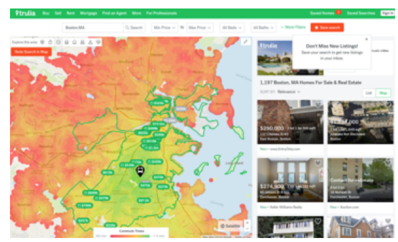


Figure D.2: The Trulia Platform provides the commute time for different transport modes from the houses that exist on the market.

Planning practitioners have much to gain from getting acquainted with these types of access tools. Practitioners can encourage companies to use and develop them, and initiate arrangements with companies aimed at sharing databases and technical knowledge. In these ways, practitioners not only increase the ability to more effectively work with business and influence the future of the economy but also help public organizations benefit from technological developments and best practices developed by the private sector.

D.1.2 Audience: Transport and Land Use Professionals

Access tools for practice are those designed for use by professionals.[4] Purposes of professionally-oriented access tools could be to audit, monitor, and set standards for land use, transport and financial policies, based on access criteria. They can be instrumental in informing not only land use and transport planning processes but also transport engineering and design and social, economic, health, and education matters.

[4] A systematic review of European accessibility tools for planning practice was conducted during the *COST Action TU1002 Accessibility Instruments for Planning Practice*. A brief review of the tools is provided in Papa et al. (2016).

Professionally-oriented access tools have been developed with an eye toward geographical scales that can range from the neighborhood to the national scale. Many examples can be found in the UK, where the access criterion was added to national policy objectives in 1997; since then the importance of access metrics within appraisals has been growing, and this use has, in turn, helped the development of several access tools.[5] In this context nevertheless, a national access tool still lacks. Note that in countries where a legal framework for access planning was at some stage

[5] For a complete review of UK access tools and access planning, see Hull (2005).

established, there is the tendency to find access tools covering the national scale.

Only a limited number of access tools provide multimodal access analysis; the vast majority consider a single transport mode. More sophisticated tools allow comparisons of access values for different transport modes and are sometimes able to offer multimodal trips choices (e.g., ones that start with walking, continue with public transport, and end with walking again). Single-mode tools are more common for two reasons. First, the data requirements and computational challenges of multimodal access analysis are considerable. Second, many tools are developed by stakeholders with a specific interest in promoting or studying a transport mode or service under their direct management. For example, it is unlikely that a bus or train operator competing for clients will be willing to include in its online access tool other transport modes that may perform better. For these reasons, practitioners should critically approach existing tools, and particularly single-mode tools, as they might be the product of vested interests.

Tools span a wide range of complexity and required expertise. Access tools that include a forecasting component rank among the most sophisticated. These tools require larger and more complex databases to run and operate from more elaborate programming, thus they have higher development costs. Their user interfaces are more complex, and the time and effort dedicated to learning how to use them can be considerable. Due to their greater complexity and implementation/maintenance costs, these tools, particularly when designed from scratch, tend to cover a limited geographical range, typically a metropolitan area.

In the policy paradigm monetary analysis of costs and benefits is of critical importance for decision making. The typical outcome is that formal cost-benefit analysis (CBA) concerned with these developments ends up considering only the costs and benefits of transport and mobility while remaining fundamentally blind to access issues[6].

[6] see Geurs et al. (2012).

D.1.3 Metrics: Infrastructure-based

Access tools employing on infrastructure-based metrics are mostly used to assess characteristics of transport networks, considering one or multiple modes of transport. Such tools are only concerned with the measurement of the performance of the transport system and thus represents a partial analysis, not fully aligned with the main concepts emphasized in this *Manual*. The main advantage though

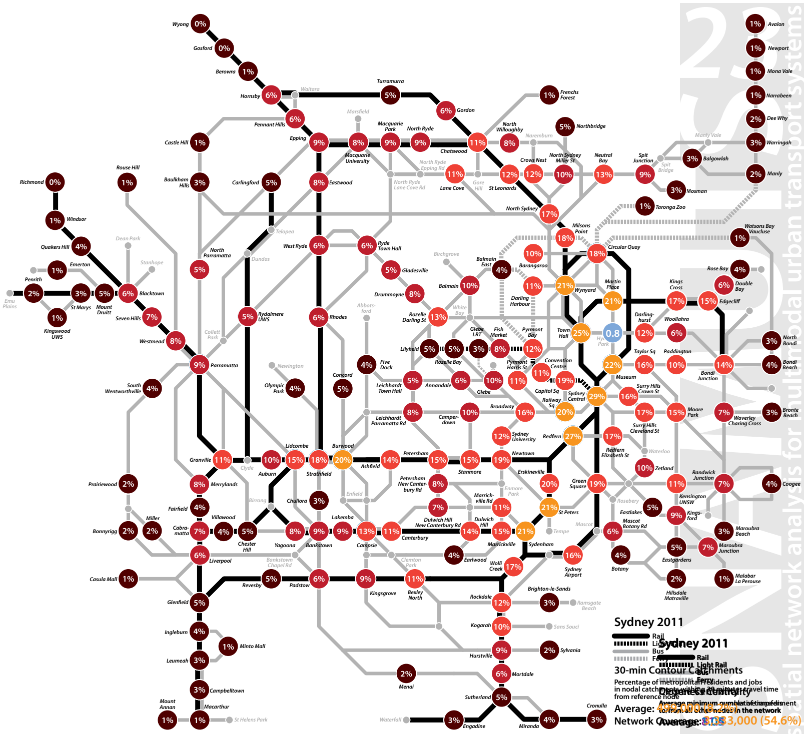


Figure D.3: SNAMUTS in Sydney. Source: (Curtis and Scheurer 2016).

is that those are moderately easy to interpret and communicate to planners and general public.

SNAMUTS. Among the tools that use infrastructure-based metric[7] is SNAMUTS (Figure D.3), a geographic information system (GIS)-based tool measuring network-based metrics. It assesses the relationship between public transport network configuration, performance, and service standards across a metropolitan area. SNAMUTS identifies and visualizes a public transport system's strengths and weaknesses in a coherent mapping exercise that considers geographic coverage, ability, and efficiency in connecting places of activity; the strategic significance of routes and network nodes; and speed competitiveness between public transport and car travel. SNAMUTS has so far been applied in several collaborative ventures with land use and transport planning agencies as well as with academic partners in Perth and Melbourne, Hamburg, Porto, and Copenhagen.[8]

[7] (Curtis and Scheurer 2016).

[8] (Scheurer 2009).

PTAL AND WEBCAT, LONDON. Another tool using an infrastructure-based metric is the PTAL – Public Transport Accessibility Level, available for the public via the London

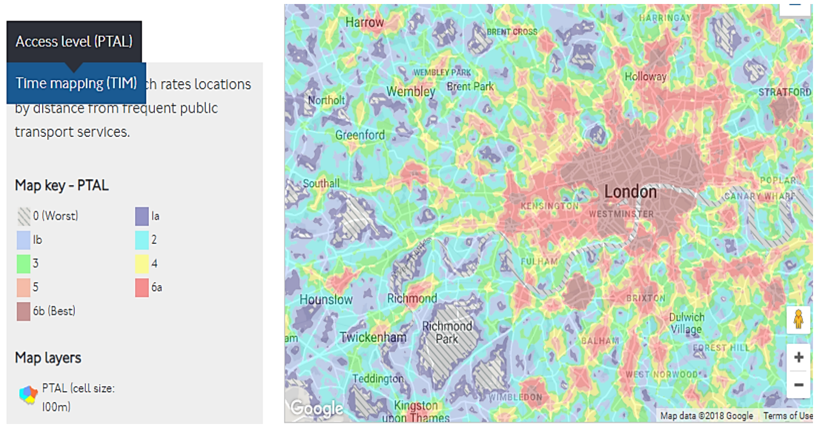


Figure D.4: London's WebCAT Mapping; London Transport's WebCAT mapping system shows the areas that can be reached by transit within a given travel time.

WebCAT, or the Web-Based Connectivity Assessment Toolkit, platform (Figure D.4). WebCAT maps the areas that can be reached by transit within a given travel time. It is used by individuals and governments for strategic planning.[9] Figure D.4 illustrates typical output.

[9] (Transport for London 2019).

PTAL is a standardized method for measuring a location's access to the public transport network (rather than a final destination), taking into account average walk speeds, distances to transit stops, and transit service frequencies.[10] This can help community planning and investment decisions. Each area is graded from 0 (very poor access) to 6b (excellent access). This method has been applied for GIS mapping in Ahmedabad, India,[11] demonstrating that such tools can function in developing as well as developed countries.

[10] (Transport for London 2017).

[11] (Shah and Adhvaryu 2016).

D.1.4 Metrics: Location-based

Tools employing location-based metrics are mostly used in land use planning with the aim of performing 'destination summation' analysis (for example, how many primary schools one can access from a given origin within 30 minutes of traveling time). Some of these tools simultaneously measure access to multiple destinations (shops, schools, parks, medical care, etc.) and create an overall access score so that different neighborhoods or geographic locations can be compared in terms of the relative opportunities and advantages they offer to residents and businesses.

Tools based on cumulative opportunities metrics are very popular in urban planning and act as a proxy for a more complete (but data intensive) measure that has a strong theoretical basis.[12]

[12] (Levinson and Wu 2020).

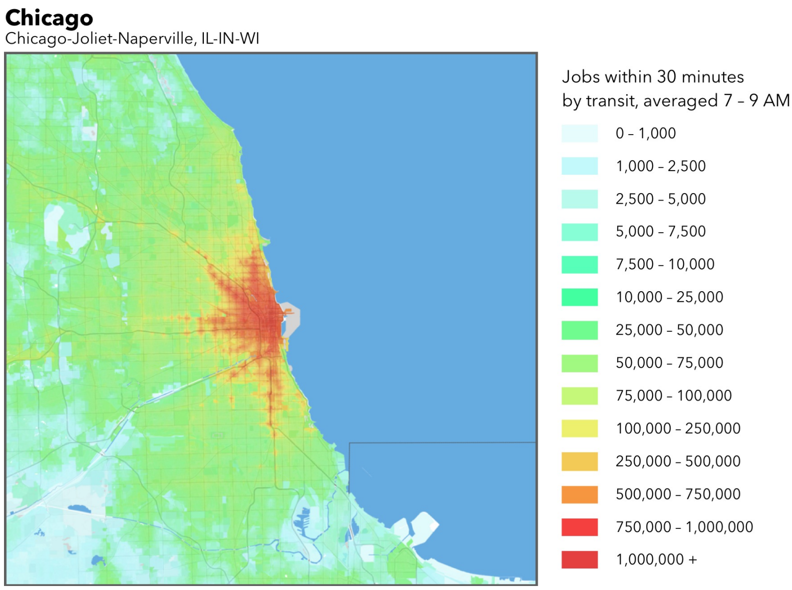


Figure D.5: Jobs within 30 Minutes by Transit in Chicago. Source: (Accessibility Observatory 2017).

Some adapted tools, though, could include features such as the behavioral dimensions and competition effects that improve their outputs. Their other main advantages are that they are easy to operationalize, interpret, and communicate.

These tools are also commonly used to perform equity analysis. Since the early 1970s, these tools have been used to assess spatial equity (differences in the spatial distribution of accessibilities) and social equity (differences in accessibilities between different population groups) issues.[13] Access tools for equity goals provide powerful means for practitioners to analyze and identify cost-effective solutions to deal with social challenges. They can also be used effectively to build hard evidence to support funding applications and to justify financial support for dealing with social exclusion problems. For these reasons those tools remain the most widely used type in planning, as demonstrated by the larger number of tools in this category.

[13] See e.g. (Palmateer 2018).

Accessibility Observatory, United States. The Accessibility Observatory includes an online mapping tool that gives users the ability to create their own maps, an interpretive website with background information and analysis, and a host of complementary features such as a storytelling project and a white paper series. Interactive maps allow users to select from a range of data layers and map features to create and view their own customized maps.

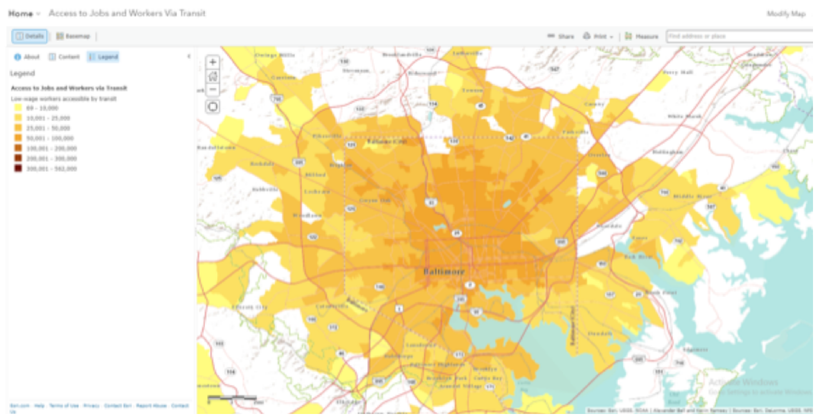


Figure D.6: EPA Accessibility Maps: Access to Jobs and Workers in Baltimore

EPA Smart Location Mapping, United States. This program of the United States Environmental Protection Agency provides interactive maps and data for measuring location efficiency, including the effects of the built environment on per capita vehicle travel, as well as methods for measuring transit access to jobs and workers.[14] A related interactive tool is available through the EPA GeoPlatform Online. The Access to Jobs and Workers tool provides access indicators for all US metropolitan areas. Figure D.6 illustrates low-wage workers accessible by transit.

[14] (United States Environmental Protection Agency 2019).

AllTransit, United States. Another US tool based on cumulative opportunities metrics, AllTransit (Figure D.8) consists of a database covering transit service in all US metropolitan regions over 100,000 in population. The platform considers the performance of transit, for example connections to other routes, jobs accessible in a 30-minute public transport ride, and the number of workers using transit to travel and allow comparison among cities.

MEP, United States. The Mobility Energy Productivity (MEP) metric[15] expands upon existing measures of access to opportunities (employment, health care, grocery, etc.) to include additional parameters such as energy consumption and total trip cost. For any given city, MEP uses information associated with land use changes, network travel times, energy consumption, and cost of travel segmented by various modes as critical inputs. The calculation incorporates all of this information to compute a MEP metric for each square kilometer 'pixel' in a given city or region.

[15] (Hou et al. 2019).

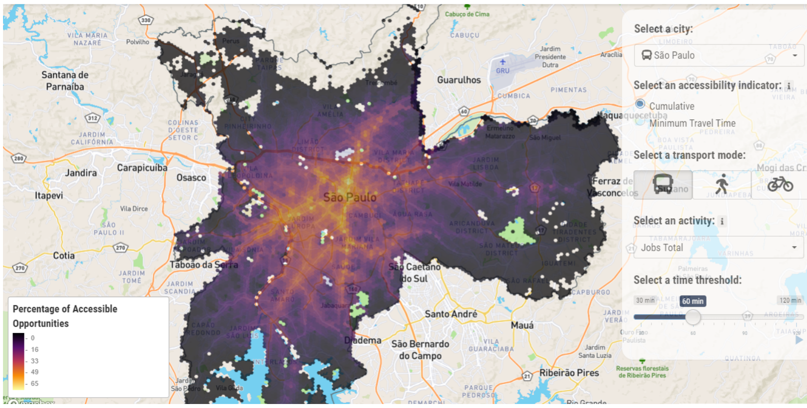


Figure D.7: Proportion of Jobs Accessible within 60 Minutes by Transit in São Paulo.

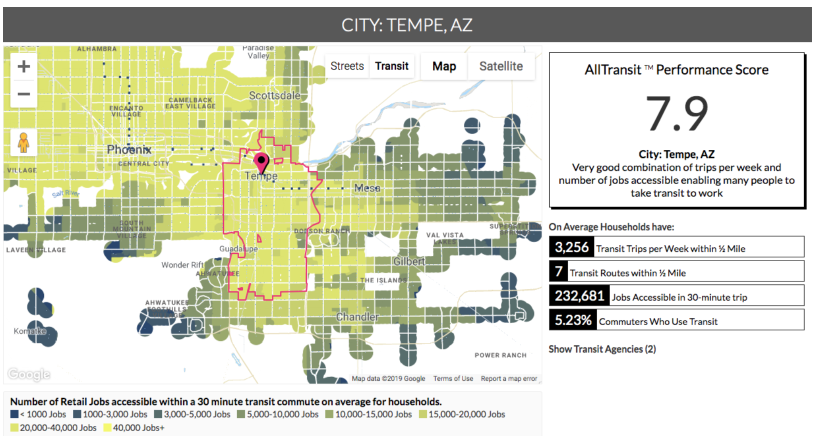


Figure D.8: AllTransit Platform Application in Tempe, Arizona. Source: CNT

Revision, Southern California. This regional mapping, analysis, and visualization program integrates a range of public and private data and performance indicators for sustainable community evaluation.[16]

[16] (UCLA Lewis Center for Regional Policy Studies 2019).

Urban Accessibility Explorer, Chicago. This mapping application displays the number of activities, including various types of jobs, schools, parks, stores and libraries, that regional residents can reach within a given travel time, by a particular mode.[17] The results are displayed on maps which can be adjusted by scale and area (Figure D.9). This tool can help policy makers, planners and residents evaluate how transport and land use decisions affect access. The Accessibility Explorer was developed by the Department of Urban Planning and Policy at the University of Illinois at Chicago to help policymakers, planners, and the general

[17] (University of Illinois at Chicago 2019).

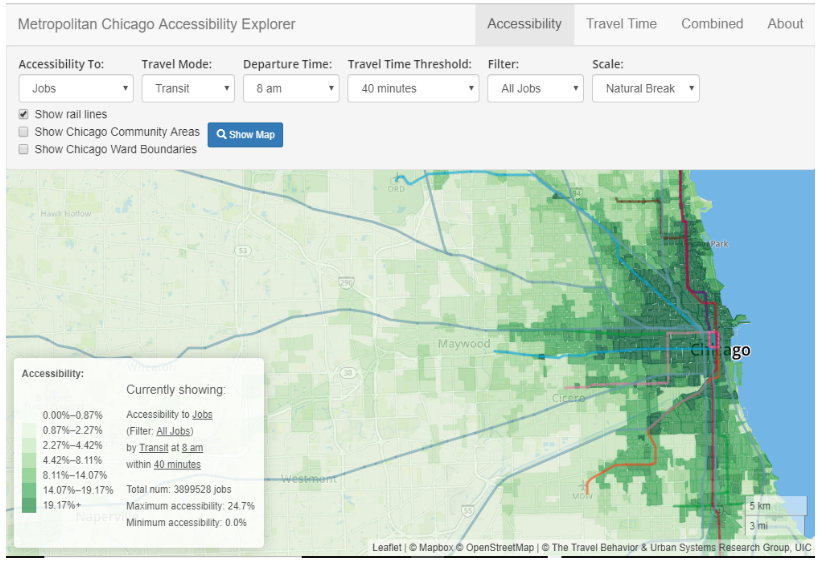


Figure D.9: Chicago's Urban Accessibility Explorer. The Urban Accessibility Explorer shows the number of activities (in this case, jobs) that can be reached within a given travel time (40 minutes) by a particular mode (public transit) in the Chicago region.

public easily evaluate how changes in the transport system and land use could alter access patterns in the region.

Access to Opportunities Project, Brazil. A similar tool outside the US context is Brazil's Access to Opportunities Project (Figure D.7).[18] The project presents annual estimates of access to employment, health, and education opportunities by transport mode at high spatial resolution for the largest urban areas in Brazil. In the first year of the project (2019), the platform covered Brazil's 20 largest cities, bringing estimates of travel time to the closest opportunity, as well as cumulative opportunities measures considering multiple travel time thresholds for walking, cycling and public transport. All data outputs and scripts are made available from the project website.

[18] (Pereira et al. 2019)

Nationale Bereikbaarheidskaart, The Netherlands. More sophisticated tools, rooted in spatial interaction models and that uses potential access metrics, have been developed in The Netherlands: this is the National accessibility tool for professional use, named Nationale Bereikbaarheidskaart. This is an online mapping tool measuring access in the present and 2020 scenarios. The access map shows the effect of infrastructure projects on development, displaying opportunities and threats that new infrastructures could pose for traffic congestion. Access is represented by the commuting time catchment area in peak and

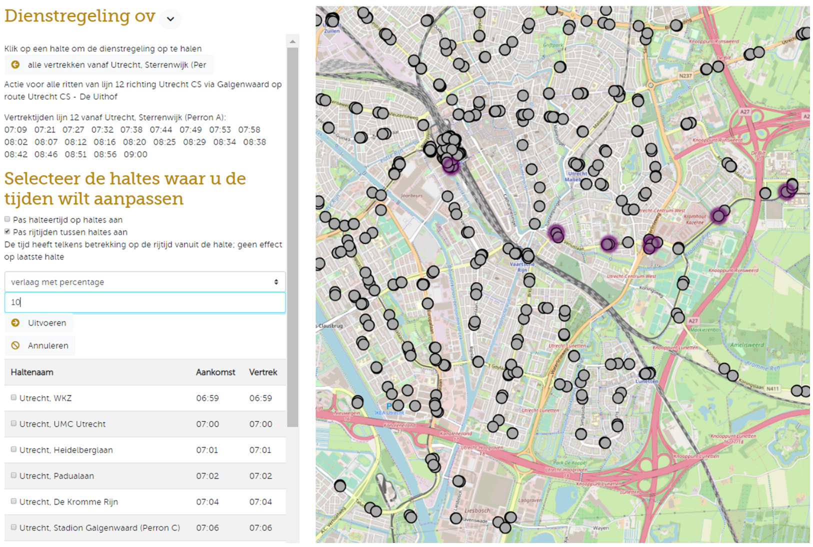


Figure D.10: Move Meter Accessibility Tool. Source: Move Mobility.

off-peak hours from a place by different transport modes, or using a combined multimodal access indicator, measuring an acceptable commuting time by a combination of driving, public transport and cycling. The access map encourages integrated spatial development and mobility decision making. This tool is mainly for use by policymakers, but also for businesses and residents.

De Verbindingswijzer, The Netherlands. Related extensions for national performance measurement of public transit in the Netherlands include De Verbindingswijzer (The Connection Guide). This tool is built using open data and open-source software, and it has been featured in Dutch Open Data competitions.

Move Meter, The Netherlands. The Netherlands also has another national scale access tool, based on a potential access metric. Move Meter (Figure D.10) is an urban development online tool that provides real-time insights into the effects of alternative scenarios where different mobility, traffic, and environmental conditions and projects can be compared.

TUM Accessibility Atlas, Munich. The Munich metropolitan region access tool also uses potential metrics, rooted in spatial interaction models, developed by the Technical University of Munich (TUM), and named the TUM Accessibility Atlas.[19] It covers the spatial scale of a region that includes an area of approximately 170 km^2 and six million inhabitants. It consists of a GIS-based

[19] (Wulfhorst et al. 2017).

platform that determines access to spatial opportunities (e.g. jobs) while considering several modes of transport. It includes a complex LUTI model and can provide scenario analysis.

D.1.5 Metrics: Utility-based

Tools which make use of utility-based access metrics can directly be used in the economic appraisal (i.e. cost-benefit analysis) of transport investments. This is a big advantage because financial aspects are a key component to be considered in access studies.[20]

[20] Other access measures require estimation of a value of access from real estate models to be multiplied by the amount of access created to determine the net benefit (in terms of land value capitalization) of access produced from, say, an infrastructure change.

A groundbreaking tool has been developed in the Netherlands as part of the economic appraisal of public transport investments for the corridor between Amsterdam Airport (Schiphol), the city of Amsterdam, and the town of Almere. The study applied the TIGRIS XL model, which produces access metrics expressed in monetary terms for use in policy evaluations.[21] The access metric is a logsum metric derived from a multinomial logit model. TIGRIS XL is fully integrated with the Dutch National Transport Model (NMS) and incorporates several components that enable an integrated analysis of demographic, land use, real estate, housing, and labour market variables.

[21] (Zondag et al. 2015).

Utility-based access tools have also some disadvantages because they are very data demanding and are less easily explained or understood.

D.1.6 Metrics: Person-based

Person-based access tools add temporal constraints to the conceptual framework of access. In most cases, these tools have been developed to measure access at the individual level partly, with the aim of overcoming the limitation of location-based metrics, which are less suited for understanding the complexities of and individual difference in human spatial behavior. Nevertheless, they are very data demanding, are less easily aggregated and communicated and less easily explained or understood.

A recent example of access tool based on this metric have been developed in Columbus, Ohio with the aim of enhancing residents' access by providing new public transit services.[22]

[22] See (Lee and Miller 2018). The work of Mei-Po Kwan is probably the most comprehensive and rich of several applications of space-time metrics of individual access for policy purposes, see e.g. (Kwan 1998).

D.1.7 Contexts: Low Data Availability

The access issues experienced in the developing world differ considerably from those experienced in wealthier countries, as are the concerns associated with developing or implementing access tools. More specifically, developing countries are being challenged by a complex combination of rapid urbanization, higher population densities, increasing numbers of motorized vehicles, congestion, and very high social inequality.[23] Some of these countries also have very different views of time value. Typically, in these countries, time is given a much lower value or — in some more extreme cases — the abstract concept of time value is not part of common sense[24]

[23] (Cervero 2013).

[24] For further insights on the topic of time value and its use in developing countries, see.(Ehn and Löfgren 2010).

Another important difference is that informal transport plays a key role in many developing countries.[25] Even though there are informal transport arrangements in developed countries as well,[26] the pattern of individuals using either their private vehicles on their own or using established public transport networks is dominant in developed countries.

[25] Robert Cervero provides a comprehensive analysis on this topic in his book (Cervero 2000).

[26] Examples of informal transport services relatively common in developed countries are the car-pooling websites Blablacar (a paid service) and Fahrgemeinschaft (a free service), which literally translates from German as 'driving community.' These online tools act as a mediator between people who want to informally arrange lifts among themselves so that they can share traveling expenses.

Another key issue for access tool implementation and enhancement in developing countries relates to data collection. The ability and willingness of both local authorities and central governments to collect the necessary data to effectively run access tools tend to be limited, representing a significant implementation barrier for access tools in these contexts. Practitioners wanting to use access tools in these environments must be aware of this and be particularly creative in the way they approach the topic with colleagues, supervisors, and policymakers. They must be aware that a good deal of 'local improvisations'[27] are typically needed to maximize the probability of successfully developing or implementing an access tool in these countries.

[27] (Heeks 2002).

Despite these issues, several access tools have already been implemented in developing countries. The World Bank developed some tools using the Open Trip Planner Analyst software in Mexico City, Buenos Aires,[28] and Lima. It now relies on a successor open-source tool to evaluate changes in access as part of the standard appraisal process for urban public transport projects.

[28] (Quirós and Mehndiratta 2015).

Because major adaptations and adjustments to context are typically needed when using already-developed tools, many of the most useful contributions to be made today in developing countries relate to gathering data and implementing new tools. Practitioners able to do this will provide remarkable contributions that are likely to change the policy paradigm in developing countries, where the focus on mobility and transport (and not on access) tend to be very unyielding. In these countries, ambitious practitioners capable of facing the challenges ahead therefore have a number of unique opportunities to make a difference.

D.1.8 *Application: Multi-actor Planning*

In planning practice, it is well recognized that decision support systems are beginning to converge with more open and collaborative characteristics. Indeed, new digital data, network tools, and interactive software promise to transform stakeholder engagement, allowing for social learning and co-creation by a broader range of experts and stakeholders and possibly, in turn, expanding the range of impacts considered in decision making.

Access tools could have a unique role in this transition because of their potential for translating broader goals into transport planning issues.[29] Access tools in tandem with other planning instruments have the capacity to provide a useful platform for interaction between experts and non-experts, and the access planning process could be the means to engage the broad social and economic community in a multi-actor environment. A key feature for future access tools is therefore 'integration capacity,' defined as the degree to which an instrument can be used as a platform to integrate different planning specializations.[30]

[29] (Straatemeier 2008).

[30] (te Brömmelstroet and Bertolini 2016).

Only a few existing access tools have high integration capacity potential, but most can be used in an interactive and co-creative planning process in which stakeholders work actively with planners to evaluate wider impacts (i.e., impacts not considered in traditional cost-benefit analyses of travel-time savings) of transport investment. The degree of interaction that the tools can support depends on their complexity and on the access metrics used.

A successful example of policy design based on access metrics in a multi-actor environment is run by the Goudappel Coffeng both in the Netherlands and in the United States.

Figure D.11: CoAXs Access Tool

Some advanced tools, such as CoAXs (Figure D.11), provide an interactive platform for discussion. CoAXs, a mapping and visualization tool developed by researchers at the Massachusetts Institute of Technology, was evaluated with focus groups of professional planners and community stakeholders in London, Santiago and Boston.[31] Online versions of CoAXs were tested in Atlanta, New Orleans, and San Francisco. The advantage of this access tool is the ease with which it can engage interested parties and the general public, in this way linking access planning to broader objectives.

[31] (Stewart and Zegras 2016).

D.2 *Access-Focused Scenario Planning Software*

The software used in access analysis can vary considerably depending on the planning goals to be adopted, the access metrics embedded in the tools, and the ways through which the tools are supposed to facilitate decision making. Regarding the architecture of access tools, there is considerable variation in terms of components. For specifying and modifying scenarios, rather than viewing pre-processed access results as in many of the tools above, there are three common types: GIS software, trip planners, and forecasting models (the latter only for more complex access metrics).

GIS software is a key element in access tools. GIS also allows linkage of socio-economic attributes of datasets to the zones, and therefore calculation of the number of opportunities that can be reached in each zone. Some free and open-source GIS software is available, such as R or QGIS.

The second fundamental component of measuring access is quantifying movement (e.g. estimation of travel time and cost matrices). Trip planners or shortest-path algorithms are embedded in many packages, such as ESRI's ArcGIS Network Analyst (now included in ArcGIS as standard), ESRI's ArcGIS for Transportation Analytics option, and Manifold's Business Tools option. Some access tools are based on spatial analysis software; examples include the tools developed by the Space Syntax Laboratory at University College London. The Space Syntax tools perform a set of spatial network analyses designed to understand the connectivity and, consequently, access of architectural or urban spaces (for example, buildings, open spaces, streets, and cities).

Note that the most-used trip planner among the access tools analyzed is OpenTripPlanner (OTP), one of the leading open source tools of its kind.[32] It is an open source platform for multi-modal and multi-agency journey planning. It provides both a map-based web interface and an application programming interface (API) for third-party applications. OTP has received investment from public agencies, startups, and transport consultancies alike. OTP relies on open data standards including GTFS for transit and OpenStreetMap for street networks. A vast number of web-based OTP deployments exist around the world. Indeed, OTP is the routing engine behind several popular smartphone applications. A further step from the same developer is the OTP Analyst that applies OTP routing engine to problems in transport planning and policies. The transit system model and optimization logic originally developed for

[32] A practical explanation on how to use OTP to create your origin-destination travel matrix can be found here.

point-to-point searches has been extended to support one-to-many and many-to-many queries. While OTP has been used widely for access analysis, its developers caution that the analysis code in OTP is "essentially an unmaintained and unsupported early prototype for later projects" with "significant technical shortcomings."

A number of specialized software applications combine the place and movement analysis:

Conveyal Analysis is open-source software, purpose-built for multi-model access calculations, that addresses some of the limitations of OpenTripPlanner. It allow gravity-based multimodal access metric and scenario analysis, importing open data from transit schedules (GTFS) and OpenStreetMap (OSM).

The open access Urban Network Analysis (UNA) toolbox for ArcGIS, can be used to calculate network access indicators, and relative visualization.

Another software able to measure access, CUBE Access, functions as an ArcGIS add-on. CUBE Access provides different types of analysis such as the metric of an Access score, a comprehensive score analysing access to multiple destinations, an Accessibility Calculator, including Travel Time Analysis, (minimum travel time to your chosen destination) and destination Summation Analysis (number of destinations with specified travel time). It also allows comparing different scenarios in one map and analyses access to new types of destinations.

TRACC, used mostly in the UK, gives accurate journey times from many origins to many destinations in a single calculation. Results are displayed in an intuitive interface and can be exported as required.

Other packages such as Caliper's TransCAD (built using the Maptitude GIS platform) and Cube (made using ArcGIS libraries) aim to provide a fully integrated transportation GIS suite with an extensive range of routing and modelling facilities.

Some access tools include a forecasting model among their components. Even forecasting models belong to the 'classic' strategic transport planning toolkit and they can be used as well as part of access tools and for access planning. These models can be used to calculate more complex access metrics.[33]

[33] Forecasting models include trip-based strategic planning models, more modern agent-based or activity-based models (such as TAPAS or MATSim), or land use transport interaction (LUTI) models. Examples of the latter are DELTA and TRANUS.

It is important to mention that a forecasting access tool might be considered as such from its stages of development. However, this is not necessarily the case. These tools might simply be pieces of software that activate a range of previously developed transport and geographical analysis tools at the same time and help them connect and feed data to each other. This is important to acknowledge because practitioners can collaborate with researchers or directly with computer experts to improve their approaches to integrate the simpler transport and geographical tools they already have into an access forecasting tool. This can be done in a number of ways, as listed below.

- In cascade. An example of this is when a demographic forecasting model produces data that is inserted in a land use and transport model that provides the input for an access analysis;
- In iterative loops. This can be exemplified by a set up where a land use model produces data that is inserted in a transport model, which, in turn, is inserted back into the land use model. This cycle is repeated time and again. This is an approach frequently adopted to predict the long-term consequences of integrated land use and transport policies.
- In parallel. This happens when several tools are used and their contributions brought together in a final output. Many Geographical Information Systems (GIS) operate like this, displaying on a single chart a variety of data types produced independently from each other (e.g. land use, demographic, and transport information).

E

Sample R Script for Dual Access Calculation

The following is an R script for calculating the dual access. Two inputs are needed for the code: a). the travel time between locations, and b). the number of opportunities within each location. The threshold number of reachable opportunities needs to be set at the beginning of the script. The script output includes the minimum travel time for reaching the threshold number of opportunities, for each location as origin.

```

rm(list=ls())
options(scipen = 999)
library("dplyr")
library("operators")
library(data.table)
setwd('PATH OF YOUR WORKING DIRECTORY HERE')
#--------------------------------------------------THRESHOLD FOR THE NUMBER OF REACHABLE JOBS
Jobs_threshold <- 30000
#--------------------------------------------------THRESHOLD FOR THE NUMBER OF REACHABLE JOBS

#------------------------READ IN TRAVEL TIME, LAND USE DATA
travel_timetable <-  read.csv(file='FILE PATH OF THE TRAVEL TIME TABLE', stringsAsFactors = FALSE,header = TRUE, check.names = FALSE)
colnames(travel_timetable) <- c('Sec','dest','origin')
#-----------TRAVEL TIME DATA FORMAT
# head(travel_timetable)
#     Sec       dest      origin
#1      0 102011028  102011028
#2   6684 102011029  102011028
#3  12351 102011030  102011028
land_use <- read.csv(file='FILE PATH OF THE LAND USE DATA', stringsAsFactors = FALSE,header = TRUE, check.names = FALSE)
land_use <- subset(land_use,select=c('SA2_MAINCODE_2016','WPP_Job'))
colnames(land_use) <- c('SA2_MAINCODE_2016','Job')
```

```
#-----------LAND USE DATA FORMAT
#  SA2_MAINCODE_2016      Job
#1          101021007      1050
#2          101021008       796
#3          101021009      5418
travel_timetable <- left_join(travel_timetable,land_use,by=c('
     dest'='SA2_MAINCODE_2016'))
colnames(travel_timetable)[4] <-c('dest_jobs')
#------------READ IN TRAVEL TIME, LAND USE DATA

#------------PREPARE FOR DUAL ACCESS CALCULATION
dualaccess_output <- as.data.frame(sort(unique(travel_timetable
     $origin)) )
colnames(dualaccess_output) <- c('SA2_CODE16')
dualaccess_output$DualAccess <- 99999  # head(dualaccess_output
     )
location_list <-  sort(unique(travel_timetable$origin))
#------------PREPARE FOR DUAL ACCESS CALCULATION

location_counter <- 1
while (location_counter <= length(location_list)) {   # -------
     loop location_counter
  travel_timetable_extract <- subset(travel_timetable,travel_
       timetable$origin== location_list[location_counter] )
  travel_timetable_extract <- travel_timetable_extract[order(
       travel_timetable_extract$Sec),]
#-------------Reachable Jobs with time increments
        w <- 0
        tempt_row_counter  <- 1
        while (w < Jobs_threshold) {
        w <- w  +  travel_timetable_extract[tempt_row_counter,'
             dest_jobs']
        tempt_row_counter  <-  tempt_row_counter + 1
        tempt_time_cost <- travel_timetable_extract[tempt_row_
             counter,'Sec']
        }
        #-------------Reachable Jobs with time increments
  dualaccess_output[location_counter,'DualAccess'] <- tempt_
       time_cost
  location_counter <-  location_counter + 1
} # -------loop location_counter

write.csv(dualaccess_output,file="FILE PATH OF THE DUALL ACCESS
      RESULT",row.names = FALSE)
```

Cal_DualAccess.R

F
Managing

This chapter provides guidelines for developing, applying, and maintaining an access measurement tool, where interrelated elements such as stakeholders, budget, and software licenses are critical.

Access tools can be built for different scales and levels of precision, not all of which require extensive institutional structure and resources.

F.1 Project Team and Stakeholders

For either developing new tools from scratch, or adapting existing tools for use in a new context, few organizations will have the full range of capacities, resources, and expertise needed to carry out the project on their own. Consequently, a team of partners with complementary roles usually conducts the tool development or adaptation process. Because access is a multi-dimensional concept requiring diverse skills and resources, access planning projects tend to be most successful when various stakeholders can collaborate across silos, considering the full range of strategies for improving access (see section 1.5). Research on the usability and impact of access tools around the world has shown that engaging and supporting stakeholders is critical, and that this engagement leads to improved tools.[1]

[1] For an extensive review of tools based on numerous local workshops in Europe and Australia, see te Brömmelstroet et al. (2014) and Papa et al. (2017).

Projects to develop, apply, and maintain access tools require a specific set of skills and capacities, and the project team should include people and organizations that can fulfil these requirements. Additional partnerships or contracts with external consultants may be needed for roles that project partners cannot fill. Project teams typically consist of organizations acting as:

- PROJECT LEADER responsible for team management and stakeholder engagement (e.g. a local authority, department of transportation, consultancy, nonprofit organization, or foundation). The project leader is often a partner with strong relationships to community stakeholders, professional networks, and actors in other institutional structures responsible for access factors (see section 1.5). For example, a project leader for a city's accessibility tool should have strong ties to departments responsible for land-use planning, public works, and transit operations. The project leader's key staff usually has a research and policy background and is responsible for developing appropriate access performance standards (see section 2.3).

- DATA MANAGER (e.g. an academic institution, think tank, government agency, nonprofit, or private data manager). Data partners have expertise in data collection and preparation and in most of the analyzed cases are national data or statistics centres or big data companies, depending on the type of data. They are responsible for data research, preparation, collection, and documentation.

- SOFTWARE DEVELOPER (e.g. an academic institution, think tank, government agency, consultancy, or software company). Software developers are experts in geographic information systems and other software used by the access tools. They are often responsible for tool development and maintenance, interpretation and analysis of data and maps, website development, outreach, training, and other support.

Managing cooperative engagement among diverse stakeholders is not simple. In a fragmented institutional context, the practical use of access metrics is often constrained by status quo regulatory frameworks, policies, and objectives. Cross-sectoral collaborations for access planning may clash with established administrative procedures or be considered a low priority.[2] Despite these potential challenges, engaging stakeholders can have multiple benefits:

[2] (Halden 2011).

- Building credibility as an inclusive, participatory effort.
- Gathering suggestions on use cases, practical constraints, and implementation considerations.
- Connecting with potential partners, supporters, contributors, and clients.

- Understanding how the project can most effectively impact policy and planning.

F.1.1 Guidelines

Critical.

- Ensure the team has key staff for project leadership, data collection and preparation, and software development.

Recommended.

- Involve stakeholders during project planning and throughout tool development.
- Consider various methods for gathering feedback and building buy-in, including topic-specific focus groups and listening sessions; individual meetings with issue experts, decision makers, and opinion leaders; formal presentations; and user experience workshops and training sessions.

F.2 Budget and Resources

Accessibility tool project budgets can vary significantly depending on the scale and scope of the project and the level of in-kind contributions from project partners. Project budgets should include funding to cover project management, stakeholder engagement, software development, data collection and preparation, interpretation of results, computation and online hosting, communications and branding, training, and ongoing maintenance. Funding sources may include local or national government contracts, research grants, and for commercial providers, user subscriptions or licenses.

User expertise and training requirements also vary. While some tools are designed to allow users without specific technical expertise to operate them and interpret results, others are designed for users with specific skillsets (e.g. familiarity with geographic information systems). In the past, ad-hoc tools to compute access have typically needed a high level of expertise to develop and operate them. Newer tools are making it easier to evaluate the access impacts of transport investments and land use changes. These calculations are taking increasingly less computational time while the software itself is becoming increasingly more affordable.

In particular, game-changing developments are taking place within open-source and other affordable software packages,[3] offering options for agencies with lower budgets. The combination of open data and open software can reduce the monetary costs of developing or adapting an access tool, though there may be substantial costs in terms of staff time and effort for configuration and customization.

[3] Some open access applications can be downloaded for free from GitHub, a large open source community of users.

Even though at present there is considerable variation in the level of expertise and costs required to develop and operate access tools, in the short-to-medium term one can expect these tools to become better, simpler to use, and more affordable.

Solicitations for access platforms should clearly specify the required scope. Subsequent project work plans should include the detailed tasks needed to achieve project goals, a timeline, and roles and deliverables for each partner and contributor. A detailed overview of the budget for a regional equity atlas is provided here. An example request for proposals (RFP) for a department of transportation procurement of a customized access platform is included as appendix G.

F.2.1 Guidelines

CRITICAL.

- Ensure the project budget covers project management, stakeholder engagement, software development, data collection and preparation, interpretation of results, computational resources such as online hosting, support and training, and ongoing maintenance.

RECOMMENDED.

- Consider an iterative project delivery approach, where stakeholders can provide feedback at multiple phases of tool development, rather than a single hand-off at the end of a project.

F.3 Software Installations and Subscriptions

Relevant considerations for access software include whether it is a locally installed program or a web-based hosted services, and whether it is closed-source or open-source. More details about specific software tools are included in Appendix D.2.

Accessibility calculations can be performed with specialized software software installed directly on users' machines. This approach is common with traditional, widely used transportation modeling and GIS software. In contrast, online hosted services are accessed through web browsers, without the need to install specialized software on users' machines, which can facilitate collaboration across agencies and organizations. In some cases, browser-based tools are sold not as software products, but as part of a service. Other online platforms allow the possibility of directly buying custom access maps for a given area. For both locally installed programs and hosted services, cost may be based on licenses or subscriptions for a certain number of seats or users.

Closed-source means the source code for software is not published or freely available for modification and re-use. Open-source means the source code for a tool is licensed for free modification and re-use. User communities of open access software often provide technical support, guidance, and updates. The relative ease of accessing open source software means it has the potential to be a common tool used by both professional planners and community groups. For example, online collaboration (e.g., collaborative mapping projects), GIS, and data visualization tools are leading to the fusion of the data collection, analysis, and representation steps of project planning, with considerable reductions in costs. In cases where open-source software still requires costly effort to customize and configure, freely available source code may improve transparency and reduce concerns of vendor lock-in.

F.3.1 Guidelines

Recommended.

- Obtain shared software that can be used by multiple partner agencies, and consider coordinated procurement to achieve economies of scale.
- Consider ways to make access analyses easily reproducible by stakeholders, such as adopting open-source tools.

G
Sample RFP for Accessibility Platform

The following pages are a Request for Proposal (RFP) issued by the City of Los Angeles in June 2019, entitled "Task Order Solicitation - Measuring Accessibility Platform." This RFP provides an example of how to specify the scope and timeline for access platform customization and a 3-year license or subscription.

1.0 INTRODUCTION

The City of Los Angeles Department of Transportation, hereinafter referred to as LADOT, seeks Task Order Proposals from the *Transportation Technology Services - Data Technologies* Bench to develop a user-friendly, GIS-based mobility and accessibility software tool. The primary features of the platform will include the following abilities: define and measure metrics of accessibility, calculate quantifiable accessibility scores across transportation modes and time, and compare different scenarios. This Task Order Solicitation outlines the scope of work, requirements, selection process and documentation necessary to bid on this project. All Task Order Proposals are due July 1, 2019.

2.0 SCOPE OF WORK

2.1. BACKGROUND

LADOT is committed to delivering transportation projects that are consistent with the City's Mobility Plan 2035[1] and reflect the goals and values embedded in the Department's Strategic Plan. With an unprecedented level of investment in the transportation sector and an on-going transition in measuring transportation metrics, LADOT aims to employ various decision-support tools to inform transportation investments and land use planning policies in achieving the city's mobility policy framework. With these tools, LADOT plans to assess the potential investment effectiveness through different lenses, including the improvement of access to destinations by different modes of travel. One such decision-support tool will be a GIS-based software used to aid analysis of transportation mode accessibility and mapping gaps in different modal networks.

2.2 SCOPE OVERVIEW

The Proposer will be responsible for developing a GIS-based mobility and accessibility software platform for LADOT's use in planning and prioritizing transportation projects. The platform will provide metrics of accessibility, calculate accessibility scores across transportation modes and time, and analyze different planning scenarios. The Proposer will incorporate local travel behavior data to adjust the accessibility score based on local conditions. The platform should include additional features that allow for customized analytical approaches for measuring accessibility and evaluating network changes.

2.3 SCOPE OF SERVICES REQUIRED

The Proposer shall provide details on how they will most effectively provide and coordinate the following key components, per the descriptions below. The Proposer is responsible for providing a GIS-enabled software platform that measures accessibility outcomes across different travel modes that responds to transportation and real estate investments and land use policy changes. The final product should include, but not be limited to, the following:

Task 1: Accessibility Platform Parameters

Define accessibility platform parameters for multi-modal work and non-work access based on the City of Los Angeles's planning framework as defined in the Mobility Plan 2035, and most updated community plans, as well as the development review procedures as defined by LADOT's Transportation Assessment Guidelines. The accessibility platform should measure accessibility outcomes (that include both mode sensitive travel time and spatial proximity) across different travel modes and should respond to transportation and real estate investments and land use policy changes. The platform should include desired

---

[1] City of Los Angeles Mobility Plan 2035. https://planning.lacity.org/documents/policy/mobilityplnmemo.pdf

components such as demographics, travel time across multiple travel modes, user sensitivity in evaluation of comfort, cost and time for all travel modes, spatial proximity, existing public transit networks, population and employment density, and specific 'points of interest' land-uses to define accessibility measured in quantitative form.

Deliverable: Define a variety of basic and advanced accessibility-related metrics that can be applied in GIS software platform to produce quantitative measure of multi-modal work and non-work access.

Task 2: Platform Customization

The Proposer shall customize the accessibility platform to respond to the City's various planning needs. The platform will need to be sensitive to both large-scale and small-scale investment decisions or policy interventions. Local data shall be incorporated to ensure that the platform accurately reflects the existing conditions in the City. The platform will need to demonstrate improvement of an accessibility score for work and non-work trips across multiple travel modes as a result of mobility improvements at the block level. Potential use cases include measuring access changes and outcomes for the following exercises:

- Development review: New land use and public right of way capital investments at a site or block level, such as:
  - Providing underserved areas with needed land uses;
  - Improving transit, bicycle and/or pedestrian facilities, such as new protected phase mid-block crossings; and
  - Locating in low-SOV zones, where non-auto modal accessibility is high
- Land Use Scenario Planning: Comparing accessibility across multiple land use plan scenarios
- Capital Project Planning: Transportation infrastructure investments related to street design on a block, corridor, or network level
- Expansion of transportation/transit services: Addition of new publicly accessible transit options such as bike-share or rail, as well as modifications to existing transit services to operate more efficiently or provide greater access

Deliverable: Platform customization to satisfy the City's planning needs related to development review, land use scenario planning, capital project planning, expansion of mobility and transit services.

Task 3: Data Acquisition and Documentation

The Proposer shall investigate, document, and acquire data sources necessary to develop the accessibility platform. The Proposer will prepare a draft data acquisition, collection, and inventory strategy for review and approval by LADOT staff. Once the strategy is approved by City staff, the consultant shall acquire and inventory data as specified, creating a Data Inputs Inventory and Data Dictionary. The Data Dictionary will include a description, data source, field attribute definitions, and other significant information on inputs required by LADOT staff.

Deliverables: Draft Data Acquisition, Collection, and Inventory Strategy; Acquire Data; Final Data Inputs Inventory; Data Dictionary

Task 4: Three Year License for GIS Enabled Software Accessibility Platform
The Proposer is responsible for providing LADOT a minimum three-year license of a GIS-enabled software platform that measures accessibility outcomes of work and non-work trips across different travel modes that responds to transportation and real estate investments as well as the land use policy changes and exercises specified and described throughout the scope of services.

Deliverable: A minimum three year license for GIS enabled software platform including various means of measuring, quantifying, and analyzing accessibility based on existing or modified transportation network and land-use conditions incorporating specific customization outlined in the full scope of services.

Task 5: User Guide and Training
Supplemental to providing the software, the Proposer shall develop a software user guide and provide training for LADOT staff to perform the software functions and features. For the training, LADOT will provide the office space (location to be determined), but the Proposer will be required to provide all necessary hardware, software and required licenses to accommodate and provide direct hands-on training for staff. Additionally, Proposer will provide a minimum of 8 hours of over-the-phone support after LADOT has acquired and begins using the software.

Deliverable: A software user guide and minimum of 8 hours of training for 25-30 LADOT staff to perform software functions and features.

3.0 QUALIFICATIONS
This project requires the Consultant to have the following qualifications/skills/knowledge and that these qualifications be demonstrated through references, resumes, and prior sample work:

- Extensive experience with web-based GIS software as a means of analyzing transportation modal accessibility
- Knowledgeable of and conversant in multi-modal transportation networks and planning
- Experience with developing decision-support tools to conduct project prioritization
- Ability to start the project immediately upon award of the notice to proceed
- Ability to develop an achievable work plan and meet or exceed project deadlines as outlined in the project schedule
- Proven record of submitting project deliverables in a timely manner

4.0 SCHEDULE
The project shall begin July 24, 2019 and must be completed by June 30, 2020.

5.0 SOLICITATION RESPONSE SCHEDULE & REQUIREMENTS
The following is the tentative solicitation response schedule:

Issue Task Order Solicitation	June 3, 2019
Question Submittal Period Ends	June 13, 2019
Q&A Response Provided	June 17, 2019
Receive Task Order Bids	July 1, 2019

Conduct Interviews (Optional)	July 10, 2019
Finalize Selection	July 17, 2019
Issue TOS Notice to Proceed	July 24, 2019

Solicitation responses must be bound and not exceed 40 pages, exclusive of cover, dividers and resumes. Three copies and a Thumb drive of the documents in PDF must be submitted no later than 4pm (PST) on July 1, 2019 to:

Los Angeles Department of Transportation
Contract Administration
100 South Main Street, 10th Floor
Los Angeles, California 90012
Attention: Angela de la Rosa

Bound solicitation responses must include:
Cover Letter: A cover letter/statement of interest, signed by an officer of the firm, indicating the firm's interest in the project and highlighting its qualifications to perform this project.

Section 1: Project Understanding & Approach: Explain your understanding of the scope of work. Discuss in detail the proposed approach and methodology to complete each task in the scope, expand the scope as needed to accommodate the proposed approach and methodology.

Section 2: Related Experience: Describe similar projects you or your firm have recently completed and your record of compliance to budgets and schedules on those projects. List no more than five (5) relevant project experiences.

Section 3: Project Team: Provide project team background, resumes, roles and responsibilities. Identify the team leader and specify the hierarchy of the proposed team structure. Provide a statement of commitment that proposed staff and sub-consultants will be retained on the project for its duration unless a substitution is pre-approved by LADOT. Include resumes of all key personnel who will be assigned to the project in the Appendix as noted below.

Section 4: Fee Estimate: Provide fee breakdown table by task and sub-task summarizing scope of work activities by discipline and by sub-consultants. Include number of hours and hourly rate for each staff member.

Section 5: Schedule: Develop and provide a detailed schedule reflecting all tasks, sub-tasks and deliverables and final project plan. The project should be completed during an **12-month** period upon receiving the Notice to Proceed letter. In order to be considered for selection, bidders must include a proposed project schedule in the proposal. The schedule shall be refined at the initiation of the project if necessary and at the discretion of LADOT.

The following response requirements are excluded from the page limit and shall be submitted in the Attachments to the proposal:

a. **Non-Collusion Affidavit (Attachment A)**
b. **Resumes (Attachment B)**

6.0 SELECTION CRITERIA

Proposals will be evaluated based on the overall best value to LADOT based on the criteria set out in this Task Order Solicitation or otherwise reasonably considered relevant. Proposals should be direct and concise while providing complete and detailed descriptions of the Proposer's abilities to meet the requirements of this Task Order Solicitation. LADOT will evaluate Task Order Proposals based on the following criteria:

	Criteria	Weight
1	**Consultant Experience:** Qualifications of the firm(s) and the staff members who will be performing the work; availability of the proposer/team and staff members to complete the proposed work within the project schedule; and the Team's technical expertise and experience as it relates to the scope of the project as demonstrated by the solicitation response.	30%
2	**Quality of Approach & Methodology:** Consultant's understanding of project need, and the issues and work required as described in this scope; depth and breadth of the proposed approach; and, appropriateness of the proposed methodology to the technical and analytical tasks required.	25%
3	**Understanding of Functional & Technical Requirements:** Consultant's understanding of the technical requirements, including the desired functions and system preferences for the solution, including supporting future needs and integration.	20%
4	**Past Performance:** Past performance and working as a consultant on similar projects in respect to quality, budget and schedule.	15%
5	**Value of Services and Cost:** The value offered to the City considering cost in comparison to professional capabilities and experience of the project team.	10%
	Total	**100%**

7.0 GENERAL REQUIREMENTS

7.1 Subcontracting

We encourage prime contractors to consider teaming with firms that have experience in any of the objectives outlined in the Scope of Work. All proposers must submit the hourly rates and a clearly-defined scope of work for all sub consultants.

As provided by the City of Los Angeles' Business Inclusion Program, LADOT strongly encourages prime contractors to subcontract with Minority Business Enterprise (MBE), Women Business Enterprise (WBE), Small Business Enterprise (SBE), Emerging Business Enterprise (EBE), Disable Veteran Business Enterprise (DVBE) in performing work for this project. The Office of Contract Compliance's Centralized Certification Administration (CCA) maintains a directory of MBE, WBE, EBE, and DVBE certified firms. Please contact CCA at (213)-8547-2684 or by e-mail at bca.certifications@lacity.org for assistance.

7.2 Cost Proposal

The compensation for services provided under this Proposal must be either based on Lump Sum Method or Cost Reimbursement Hourly Billing Rate Method. Prior to executing the Task Order Agreement, parties must reach an agreement on the method of compensation. There is $225,000 allocated for this Task Order.

Proposers must prepare a Cost Proposal worksheet summarizing the tasks outlined above, with staffing, estimated hours, and rates (including proposed sub-consultants). Staff roles and rates must not deviate from Appendix D of the On-Call Transportation Technology Services contract.

Direct Expenditures must be a standalone category in the task order proposal, and therefore must not be substituted or mixed with other costs in computing the percentage of completion under Lump Sum Method of invoicing method.

8.0 SOLICITATION ADMINISTRATOR

[redacted] Contract Administration
Los Angeles Department of Transportation
100 South Main Street, 10th Floor
Los Angeles, CA 90012

All questions related to this Task Order Solicitation must be submitted no later than 4pm on June 13, 2019 via e-mail to David Somers at david.somers@lacity.org and [redacted]. Please indicate the following in the subject line of your e-mail: "Measuring Accessibility Platform – TOS Questions." LADOT may combine and re-phrase similar questions into a single question with an appropriate response to be provided to all parties who were sent this solicitation. Responses will be delivered via email.

9.0 DISCLAIMER

The Task Order Solicitation does not commit the City to proceed with the project, pay any costs incurred in the preparation of a response to this request, or to procure or contract for further services. The City reserves the right to accept or reject any responses received as a result of this solicitation or to cancel this solicitation in part or in its entirety.

The City may or may not elect to award any or part of this Task Order based on its sole convenience and shall not be responsible for any solicitation response costs.

10.0 ATTACHMENTS

Non-Collusion Affidavit

H
Further Reading

If you want to explore more about accessibility, the following books and articles listed in this chapter may be of interest. These reading material are organized into three topics:

- Theory of Access
- Applying Access
- Transport Affordability

Within each topic category, the reading material are organized in reverse chronological order.

Theory of Access

- Transportation Research part D has a special issue on Accessibility in 2020. Transportation Research Part D: Transport and Environment | Planning for Accessibility
- Jeff Allen and Steven Farber. A measure of competitive access to destinations for comparing across multiple study regions. *Geographical Analysis*, 52(1):69–86, 2020
- David M Levinson and Hao Wu. Towards a general theory of access. *Journal of Transport and Land Use*, 2020
- Mengying Cui and David Levinson. Primal and dual access. *Geographical Analysis*, 52(3):452–474, 2020
- Mengying Cui and David Levinson. Multi-activity access: how activity choice affects opportunity. *Transportation Research Part D: Transport and Environment*, 85:102364, August 2020
- Hao Wu and David Levinson. Unifying access. *Transportation Research Part D: Transport and Environment*, 83:102355, 2020
- Indaco Biazzo, Bernardo Monechi, and Vittorio Loreto. General scores for accessibility and inequality measures in urban areas. *Royal Society Open Science*, 6(8):190979, 2019
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- Revision is a regional mapping and analysis program that integrates a range of public and private data for sustainable communities planning and trend visualization. It provides a common regional performance monitoring tool for sustainable community indicators.

- Smart Location Mapping provides interactive maps and data for measuring location efficiency, including the effects of the built environment on per capita vehicle travel, and methods for measuring access to jobs and workers by public transportation.

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