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Practical Measures for Advancing Public Transit Equity and Access

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JULY 2023

U.S. Department of Transportation
Federal Transit Administration

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C

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14. ABSTRACT
In partnership with the Federal Transit Administration, researchers at the University of Texas at Austin, Arizona State University, and Dunbar Transportation Consulting, LLC, identified a set of replicable measures that public transportation providers and their partners can use to advance equity for those who have been historically underserved, marginalized, and adversely affected by persistent poverty and/or inequality. These include practical strategies such as advisory committees and intergovernmental partnerships as well as analytical techniques that quantify how public transit links people to opportunities.

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Abstract

In partnership with the Federal Transit Administration, researchers at the University of Texas at Austin, Arizona State University, and Dunbar Transportation Consulting, LLC, identified a set of replicable measures that public transportation providers and their partners can use to advance equity for those who have been historically underserved, marginalized, and adversely affected by persistent poverty and/or inequality. These include practical strategies such as advisory committees and intergovernmental partnerships as well as analytical techniques that quantify how public transit links people to opportunities.

Executive Summary

In partnership with the Federal Transit Administration (FTA), researchers at the University of Texas at Austin, Arizona State University, and Dunbar Transportation Consulting, LLC, have identified a set of replicable measures that public transportation providers and their partners can use to advance equity for those who have been historically underserved, marginalized, and adversely affected by persistent poverty and/or inequality. These include practical strategies such as advisory committees and intergovernmental partnerships as well as analytical techniques that quantify how public transit links people to opportunities. This project seeks to implement Executive Order 13985: Advancing Racial Equity and Support for Underserved Communities Through the Federal Government and the U.S. Department of Transportation's Equity and Access Policy Statement.

Objectives

The purpose of the project is to provide decision-makers in planning organizations and public transportation agencies, as well as other stakeholders and the public, with step-by-step methods and examples that illustrate how equity can be prioritized and assessed in decision-making processes.

The measures target equity practices and spatial analysis of public transportation system performance.

- Equity practices – The report describes nine strategies that planning organizations, public transportation providers, and partners can pursue to advance equity objectives: advisory committees, fare policies, intergovernmental partnerships, leadership champions, advocacy partnerships, regional planning, capital planning, ride-hailing and microtransit, and creating an equity culture.
- Spatial analysis – The report demonstrates the application of five quantitative spatial measures for evaluating public transportation system performance: population counts/shares; access to opportunities; trip characteristics using census data; trip characteristics using transit rider surveys; and user benefits based on logsums. The measures are calculated using open-source and/or freely available methods and data.

The research team solicited input and shared progress with key stakeholders throughout the course of the project. Several public transportation providers and one community-based organization provided interviews, data, and analytical feedback that form that basis of the case studies highlighted here. In addition, the project team regularly consulted both a Technical Advisory Group and a Community Advisory Group, each comprising expert practitioners from public, private, and academic sectors over the course of the project. See Appendix B for further information.

Key Findings and Conclusions

- While most organizations would agree that advancing transportation equity is important, there are a variety of approaches for its achievement and few systematic reviews that seek to understand just how effective different measures are at advancing equity goals.
- How a community defines, develops, and applies data can shed light on existing conditions and promote progress toward a desired future state. The data that organizations collect, and the structure of various analyses, have a major influence on our understanding of who uses public transportation services and how those individuals might be impacted by changes to those services, especially people who depend on public transportation services.
- Collecting local ridership data through survey tools is the best method for considering demand for public transit and the demographics of existing transit users in data analyses. The existing Title VI ridership survey requirement is an ideal platform for developing better local data about the people who already rely on public transportation services.
- There is a lack of data related to the continuity and quality of sidewalk infrastructure, especially at a level of detail to reveal its usability for those traveling with mobility devices, including wheelchairs. These data are essential, as navigable sidewalks are critical for accessing public transportation services and achieving complete trips. This lack of data warrants further attention.
- Strong partnerships between local organizations and transportation planners and providers can inform the understanding of community goals and needs, shape data collection and analysis, and in turn inform plans, programs, projects, and services. Ongoing dialogue is critical for developing, interpreting, and applying what the data reveals.
- Agencies regularly conduct quantitative spatial analyses to comply with equity requirements. For these analyses to move the needle on key equity outcomes, they must be paired with broader institutional practices rather than stand on their own.
- In cooperation with Houston Metro and FTA, the project team evaluated Houston Metro's System Reimagining for the spatial analysis case study. The team piloted the use of FTA's Simplified Trips-on-Project Software (STOPS) model for calculating user benefits based on logsums.
- Overall, the most important measure of success for more equitable outcomes is an organization's willingness to make equity an overarching, system-wide goal to pursue on multiple fronts.

Section 1 Introduction

Public transit agencies seek to serve the public interest by providing affordable mobility to populations within their service area. This mobility is essential for facilitating access to opportunities across municipalities and regions, enhancing economic competitiveness by providing alternatives to driving, and improving quality of life and well-being, especially among those who cannot or choose not to drive a car [1, 2]. At the same time, investments in transportation infrastructure confer different benefits and burdens upon local and regional populations depending upon the infrastructure's location, mode, level of service, and the extent to which these align with travel needs and ability to pay [e.g., 3]. Transportation equity is a broad concept that refers to ensuring the benefits and burdens associated with transportation investment are distributed across population groups and locations such that no one group is disadvantaged by a lack of access to the transportation resources needed for a better quality of life.

Quantitative and qualitative performance analyses of investments and their effects on different population groups can be important elements of regional and local efforts to ensure equitable outcomes. But quantitative analytical approaches vary widely; their scope and level of detail are flexible and determined by the agency itself [4]. Available data limit possible analyses, and key choices (e.g., related to community definition or performance measures) that appear innocuous can have a substantial effect on the results and equity determinations [5, 6]. The Federal Highway Administration (FHWA) and Federal Transit Administration (FTA), which jointly administer federal requirements for long-range transportation planning and programming, require equity considerations at the state, regional, and non-metropolitan levels. Furthermore, the Federal Transit Administration requires larger agencies receiving federal funding to perform equity analyses on proposed fare and service changes and facility siting/location decisions.

Public transit providers in the United States are not alike; they are characterized by a wide range of resources, expertise, technical capacity, modes, and population characteristics. While not all measures described in this report will be within the reach of all agencies, the work is structured with different agency types in mind. There will be lessons learned and best practices that can be applied from the largest to the smallest public transit agency ranging from complex multimodal and large urban providers to small rural agencies with mostly on-demand service.

The work presented here is the result of a three-year project sponsored by the Federal Transit Administration and completed by a team led by Dr. Alex Karner at the University of Texas at Austin. Two advisory groups were assembled to support the work, a Technical Advisory Group (TAG) and a Community Advisory Group (CAG). The TAG included experts in travel demand modeling, transportation, planning and policy, and public transit performance analysis drawn from industry, academia, and practice. The CAG included representatives of the nonprofit and advocacy sectors. Both groups were convened several times during the project to solicit and incorporate their feedback into subsequent work. The TAG largely provided insight into the spatial analysis components, while the CAG helped the research team think broadly about equity and identify limitations of the quantitative performance analyses being conducted. Additionally, the team reviewed extensive documentation online and interviewed staff at several organizations. The authors thank those interviewed for their assistance, time, and willingness to participate in this work. All featured agencies are listed in Table 1-1. Those who provided specific interviews are referenced in the works cited.

Table 1-1 *Transportation Agencies and Organizations Whose Equity Practices Are Featured in This Work*

Agency Name	Location	Organization Type
Capital Metro (Cap Metro)	Austin, TX	Public transportation provider
Champaign-Urbana Mass Transit District (CUMTD)	Champaign-Urbana, IL	Public transportation provider
Massachusetts Bay Transportation Authority (MBTA)	Boston, MA	Public transportation provider
Massachusetts Department of Transportation (MassDOT)	MA	State department of transportation
TransitMatters	Boston, MA	Nonprofit organization
LivableStreets Alliance	Boston, MA	Nonprofit organization
Metropolitan Transit Authority of Harris County (Houston METRO)	Houston, TX	Public transportation provider
Houston-Galveston Area Council (H-GAC)	Houston, TX	Metropolitan planning organization
LINK Houston	Houston, TX	Nonprofit organization
rabbittransit	York, PA	Public transportation provider
City of York	York, PA	City government
Eat Play Breathe York	York, PA	Nonprofit organization
Sound Transit	Seattle, WA	Public transportation provider
Seattle Department of Transportation	Seattle, WA	City department of transportation
Tri-County Metropolitan Transportation District of Oregon (TriMet)	Portland, OR	Public transportation provider

In addition to this introduction, this report contains four sections.

Section 2 – Key Concepts provides an overview of some of the work's underlying concepts, including spatial accessibility, civil rights, and environmental justice. It includes a discussion of relevant federal law, regulations, and guidance that govern transit agencies' pursuit of equity-related outcomes.

Section 3 – Transportation Equity Practices includes the results gleaned from interviews with public transit agency staff, nonprofit organizations, and transportation advocates from across the United States and who are identified in Table 1-1. The practices that organizations are undertaking to advance transportation equity in their cities and regions are highlighted. Table 1-2 identifies the equity practices discussed in this report with reference to the seven agencies studied.

Table 1-2 *Equity Practices and Transit Agencies Discussed in This Report*

	Equity practices								
	Advisory committees	Fare policies	Intergovernmental partnerships	Leadership champion	Advocacy partnerships	MPO planning	Capital planning	Ride-hailing and microtransit	Creating an equity culture
Capital Metro	■	■		■				■	
CUMTD								■	
MBTA	■	■	■	■	■	■			■
Houston METRO			■	■	■	■		■	
rabbittransit			■				■	■	
Sound Transit	■						■		
TriMet	■	■							■

Section 4 – Spatial Analysis and Step-by-Step Examples describes specific quantitative performance measures that can be used to aid transportation planning and project development. It outlines the data needed and steps required to calculate measures for better understanding the impact of proposed transit service changes on different demographic groups.

Recipients of FTA funds who are required to conduct service equity analyses are advised that not all the approaches discussed in this report have been approved by FTA. Such recipients should review FTA's Title VI Circular for guidance on conducting transit service fare or equity analyses.

The spatial analysis section provides example steps for calculating five performance measures using open-source and/or freely available methods and data:

1) **Population counts/shares** provide information on how many people live near public transit as well as demographic information. These measures are the easiest to calculate but do not explain how useful public transit is and who is using it.

2) **Access to opportunities** measures detail the number of opportunities that people can reach using public transit. These measures are widely used but do not incorporate information about the number of people using public transit or the types of trips they need to make.

3) **Trip characteristics using census data** incorporate information about the number of people using public transit for commute trips, their demographics, and their origins and destinations. Using this information, travel times and other trip characteristics can be calculated for public transit commuters.

4) **Trip characteristics using transit rider surveys** convey data about the number of people using public transit for all trips, their demographics, and their origins and destinations. Trip characteristics can subsequently be calculated for all transit riders.

5) **User benefits based on logsums** capture the level of freedom associated with a given set of choices, considering the entire set of modes available to complete a trip. If the number of choices or their attractiveness increases, logsums also increase. Logsums are used widely in travel demand modeling and can be extracted from the Simplified Trips-on-Project Software (STOPS) maintained by FTA. In this context, changes in logsums are often referred to as "user benefits."

Figure 1-1 summarizes the change in user benefits expected to result from a major service change as outlined in Section 4. Red areas indicate locations where travel times generally increased for the trips that people needed to make to or from those areas. Green areas indicate locations where travel times generally decreased. The measures are weighted, so locations with more people will tend to have large numbers (either positive or negative).

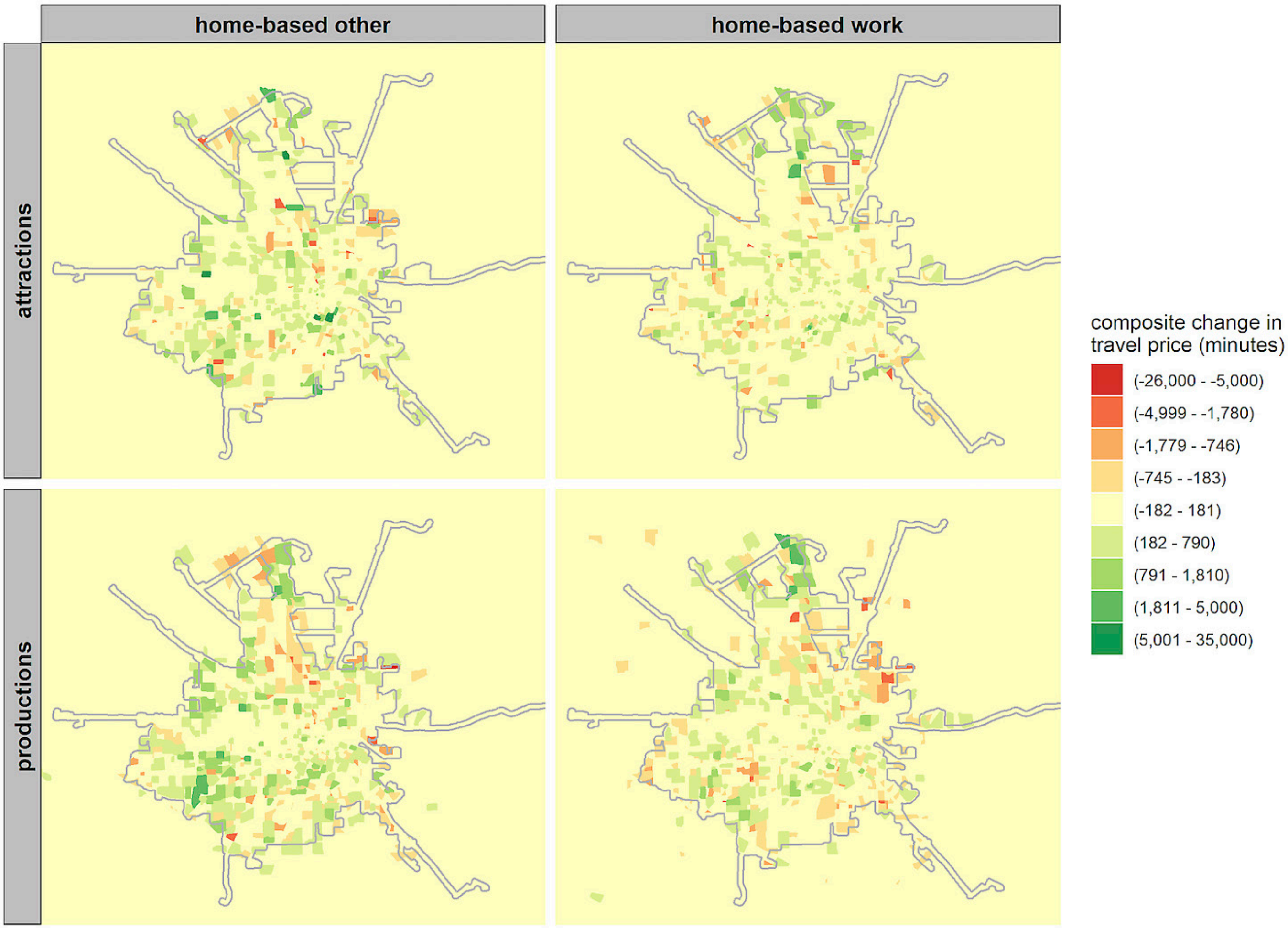


Figure 1-1 *Weekday user benefits resulting from a major bus network redesign in Houston, TX, calculated using FTA's STOPS model and Summit software*

Section 5 – Conclusions offers concluding thoughts for transit agencies and planning partners seeking to advance equity-related objectives.

Two appendices to the report summarize the literature review completed for the project and detail additional information about the TAG and CAG.

Two key aspects of this work make it different from existing tools and methods. First, recognizing the varying levels of resources and sophistication that exist across public transit agencies, the tools and recommendations are tailored to account for varying capabilities and needs, ranging from small rural to large urban organizations. In support of this effort to tailor the results, many different data sources are considered for use, depending on available agency resources. These include, but are not limited to, geographic proximity to public transit infrastructure, the Census Transportation Planning Package (CTPP), and onboard survey data. Second, in locations where such data are available, information on current and projected public transit system users are integrated into the analyses to identify more precisely how changes will affect different demographic groups. More commonly, analyses of public transit rely upon measures of “access to opportunities” without considering existing or projected transit market shares or users.

Section 2 Key Concepts

Spatial Accessibility

Transportation systems provide a vital link between people and opportunities. Travel to work, school, shopping, medical care, and social visits is needed to live a healthy and fulfilling life. Understanding how well—and for whom—existing and future transportation systems offer these vital links has been a concern of both transportation academics and practitioners since at least the 1950s [e.g., 7, 8]. The connection between people and opportunities is captured by the term *accessibility*, defined as the ability to reach destinations widely distributed in space.[1] Put simply, accessibility—connections between people and opportunities—is the most important economic and social benefit created by a transportation system and it facilitates participation in activities that individuals need to lead a meaningful life [9–14].[2]

Two Key Concepts: Network Connectivity and Spatial Accessibility

Connectivity and accessibility are two terms that are often used interchangeably but have different meanings depending on context.

Connectivity is a property of a specific transportation network and specific modes. Connectivity measures address gaps in the network and the extent to which users may move seamlessly from origin to destination. These and related measures can be helpful for highlighting conditions confronted by pedestrians and cyclists.

Spatial accessibility refers to spatial measures that reflect the ease of reaching destinations. Generally, measures that improve connectivity will also improve accessibility. But increases in connectivity or accessibility for one mode could decrease that of others, if for example a new highway facility bisects an existing pedestrian facility.

This report uses the term *accessibility* because it is more widely known, understood, and used by practitioners and academics to refer to the primary purpose and benefit of a transportation system.

Since the 1950s, scores of academic studies have been written that quantify various aspects of accessibility for both people and places [e.g., 15–19]. Accessibility indicators are also increasingly being integrated into the transportation planning process, but planners sometimes lack detailed knowledge about metrics, their inherent tradeoffs, and how to integrate them into decision-making [20–23] or communicate results to the public [24, 25]. Indeed, incorporating new perspectives and performance measures into transportation planning activities has often proven difficult [e.g., 26].

[1] As opposed to physical access to a transit vehicle or non-motorized infrastructure, which would be relevant from the perspective of individuals with disabilities and the Americans with Disabilities Act (ADA).

[2] See Appendix A for a literature review on the concept and applications.

Regarding the quantification of accessibility, analytical choices are complicated by the plethora of available measures. Some measures indicate the total number of opportunities that can be reached from a given location in space within a certain travel time threshold (e.g., 45 minutes), others weight opportunities so that closer ones are more valuable, and some consider travel only via a single mode while others might integrate all modes to arrive at a composite accessibility measure.

A key distinction that emerges in the study of accessibility is that of person versus place. *Place accessibility* reflects the ability to reach destinations from a specific origin, while *person accessibility* reflects the characteristics and constraints faced by an individual in terms of mode availability, financial resources, travel time budgets, and so on.

Travel demand models have historically provided the backbone of accessibility analysis and work best for representing automobile travel. Accessibility indicators can be as simple or complex as the data underlying them allow. The primary datasets for calculating accessibility measures used to be generated by travel demand models. Key outputs from travel demand models include regional "skim" tables that describe multimodal travel times between all origins and destinations. These travel times can be combined with measures of opportunities at each destination to create accessibility measures.

Representations of travel by public transit, walking, and bicycling are often basic or nonexistent in travel demand models and updates to transit networks in particular are onerous and must be completed by hand. These limitations mean that, historically, accessibility by automobile has been assessed much more often than alternative modes.

New data sources, however, better represent walking, biking, and public transit trips. New data sources and standards, including the General Transit Feed Specification (GTFS) created by Google and Portland's public transit provider TriMet, have produced new analytical opportunities to measure public transit system performance and accessibility [e.g., 27–30]. Most importantly, the advent of GTFS data eliminates the need to generate regional skims using a travel demand model and facilitates the creation of travel times on a desktop computer. Further advances have involved the use of automatic vehicle locator (AVL) and real-time public transit arrival and delay data. These promise to add more nuance and texture to analyses of accessibility based on posted schedules [31, 32]. Analyses of accessibility by automobile are also more feasible with the advent of the Google Maps application programming interface (API) and other online resources that facilitate real-time congestion-aware automobile travel times across a network [33]. The increasing democratization of travel data opens new avenues for analysis whose implications are only beginning to be understood.

Because of the importance of accessibility to community goals for social equity and achieving key life outcomes, the distribution of accessibility across the population and the effect of new transportation policies, plans, and programs on accessibility have been widely addressed in the literature. The overwhelming number of accessibility measures and approaches creates a barrier to meaningful analysis. Not all measures and metrics are created equal and not all are comprehensible by the public. This report presents information on several types of measures and highlights steps for employing the datasets and tools required for calculating them.

Equity determinations of the type outlined in FTA circulars can take many different forms. In general, there are few standard approaches for equity analysis at regional planning agencies and public transit authorities [4–6, 34, 35]. In practice, planning agencies have wide latitude to conduct analyses as they see fit and using whichever data are convenient and available. A compounding issue is the often-challenging technical nature of accessibility calculations, which can create challenges for communication and public involvement. Further, once the equity analysis stage has been reached, it might be too late. Meaningful and effective public involvement play an important role in achieving transportation equity prior to the completion of quantitative equity analysis [36]. In fact, public involvement is vital for identifying the needs, goals, thresholds, and other factors that will help to ensure that equity analysis and its findings are meaningful for a given community.

Relevant Law, Regulations, and Guidance

Transportation agency goals related to transportation equity are undergirded by a strong legal, regulatory, and policy foundation stemming from Title VI of the 1964 Civil Rights Act, as amended, the 1987 Civil Rights Restoration Act, Executive Order 12898 (Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations), and the Americans with Disabilities Act, among others that prohibit discrimination based on race, color, national origin, ability, age, and gender [e.g., 37]. *The Transportation Planning Process Briefing Book*, jointly authored by FHWA and FTA, defines transportation equity as follows:

> Transportation equity refers to the way in which the needs of all transportation system users are reflected in the transportation planning and decision-making process. In particular, transportation equity focuses on the needs of those traditionally underserved by existing transportation systems, such as low-income and minority households, older adults, and individuals with disabilities. Transportation equity means that transportation decisions deliver equitable benefits to a variety of users and that any associated burdens are avoided, minimized, or mitigated so as not to disproportionately impact disadvantaged populations. [38]

Clearly, transportation equity is multifaceted, but it generally calls attention to the impacts of transportation planning activities on underserved populations. Understanding whether transportation equity impacts require attention or mitigation in a specific circumstance requires both data analysis and thoughtful public involvement. The Transportation Planning Process Briefing Book states that both measures are critical to ensure that the planning process is adequately responsive to equity-related concerns. This two-pronged approach is consistent with understandings of transportation equity in the academic literature [e.g., 39]. Importantly, transportation equity emerged from earlier "environmental justice" struggles motivated by the disproportionate environmental and quality of life burdens faced by people of color and low-income people across the United States and around the world [40, 41]. These struggles were undergirded by dysfunctional and/or nonexistent public engagement processes [42, 43].

The *Transportation Planning Process Briefing Book* identifies US Department of Transportation (USDOT), FHWA, and FTA regulations, policy, and guidance detailing various requirements aimed at achieving equity-related outcomes through both public involvement and analysis. Relevant measures are summarized in Table 2-1.

Table 2-1 *Selected Citations of US Law, Regulations, and Guidance Related to Transportation Equity*

Measure	Type	Notes	Reference
Title VI of the Civil Rights Act of 1964	Law	Prohibits race, color, and national origin discrimination in programs and activities receiving federal funds.	42 U.S.C. §2000d et. Seq.
Age Discrimination Act of 1975	Law	Prohibits age discrimination in programs and activities receiving federal funds.	42 U.S.C. §6101-6107
Civil Rights Restoration Act of 1987	Law	Clarifies relationships between Title VI and other more recent nondiscrimination law.	102 Stat. 28
Americans with Disabilities Act (ADA) of 1990	Law	Prohibits discrimination against and requires equal opportunity for people with disabilities.	42 U.S.C. §12101
FTA/FHWA Joint Statewide and Nonmetropolitan Transportation Planning; Metropolitan Transportation Planning regulations	Regulations	Governs the development of metropolitan transportation plans (MTP) and programs for urbanized areas, long-range statewide transportation plans and programs, and the congestion management process.	49 CFR Part 613 (FTA's citation for the joint FTA/FHWA regulations, found in total at 23 CFR Part 450)
FTA/FHWA Joint Regulation for "Interested parties, public involvement, and consultation"		Requires MPOs and states to create a public participation plan establishing procedures for receiving and incorporating public input during the planning process.	23 CFR 450.210 23 CFR 450.316

Table 2-1 (cont.) *Selected Citations of US Law, Regulations, and Guidance Related to Transportation Equity*

Measure	Type	Notes	Reference
USDOT Title VI regulations	Regulations	Implements Title VI compliance at the USDOT and its sub-agencies.	49 CFR Part 21
FHWA Title VI program	Regulations	Implements Title VI compliance at FHWA and its grantees.	23 CFR Part 200
USDOT Americans with Disabilities Act regulations	Regulations	Implements ADA compliance at the USDOT and its sub-agencies.	49 CFR Parts 27, 37, 38, and 39
Executive Order 12898: Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations	Executive Order	Requires federal agencies to make achieving environmental justice part of their mission.	Clinton [44]
Executive Order 13166: Improving Access to Services for Persons with Limited English Proficiency	Executive Order	Directs executive agencies to identify and provide needed services for persons with limited English proficiency.	Clinton [45]; Trujillo [46]
Executive Order 13330: Human Service Transportation Coordination	Executive Order	Establishes the "Interagency Transportation Coordinating Council on Access and Mobility" to coordinate efforts across multiple agencies that fund transportation services targeted at low-income people, older adults, and people with disabilities.	Bush [47]
FTA Title VI Circular 4702.1B	Guidance document	Provides directions for FTA grantees to comply with USDOT Title VI regulations.	Federal Transit Administration [48]
FTA Environmental Justice Circular 4703.1	Guidance document	Recommendations for involving environmental justice populations in the transportation decision-making process as well as guidance for assessing impacts and disproportionality.	Federal Transit Administration [49]
FHWA Order on Environmental Justice 6640.23A	Guidance document	Establishes FHWA practices for compliance with EO 12898	Federal Highway Administration [50]

Source: Draws from the Federal Highway Administration and Federal Transit Administration [38, pp. 24–25]

Highlights from FTA's Title VI Circular 4702.1B

FTA Circular 4702.1B specifies the elements required to comply with USDOT Title VI regulations. It includes general requirements that all FTA fund recipients must follow as well as specific requirements for fixed-route transit providers, states, and metropolitan planning organizations. The general requirements most relevant to this report include:

- **Preparing and submitting a Title VI program**. The Title VI program documents an FTA recipient's compliance with USDOT Title VI regulations. In addition to standard public notices, complaint procedures, and disclosure of investigations, the program must contain a "public participation plan" that seeks to engage Title VI–protected and limited English proficiency (LEP) populations, as well as other underserved populations as appropriate for the provider. Other program requirements include reporting the racial composition of transit-related, non-elected advisory boards, describing efforts to ensure subrecipient compliance, and further details about LEP assistance, among others.
- **Promoting inclusive public participation**. Building from the requirements for a public participation plan, this section summarizes some best practices for public meetings, collaborations with nonprofit and advocacy organizations to conduct targeted outreach, and other non-meeting methods for disseminating information.
- **Determining site or location of facilities**. The requirements apply to storage and maintenance facilities as well as operations centers. The circular requires that an equity analysis be conducted during project planning that considers who will be affected by different siting alternatives and cumulative impacts. If a disparate impact is found, a siting decision can only proceed if accompanied by a "substantial legitimate justification" explaining there are no alternative locations that would have a less disparate impact.

Many of the specific requirements for fixed-route transit providers covered in the circular's Chapter IV are also relevant here, especially those that address data collection requirements. Chapter IV's requirements are meant to supplement the general requirements for a Title VI program described above. Importantly, the circular distinguishes between larger providers that operate 50 or more fixed-route vehicles in peak service and that are in a census-designated urbanized area of 200,000 people or more and those that operate fixed-route service on a smaller scale. Both types of agencies must establish standards and policies across their systems, but only larger providers are required to collect and report data, evaluate the equity impacts of fare and service changes, and monitor transit system performance. Providers that only operate demand responsive service are only subject to the general requirements described above. Chapter IV's additional requirements include:

- **Setting system-wide service standards and policies** (applies to all fixed-route transit providers). Standards and policies apply differently to each modal category that a service provider operates. Standards differ from policies in that the former are based on a quantitative threshold whereas the latter refer more generally to practices aimed at preventing discrimination. Standards must be established for vehicle load, headway, on-time performance, and service availability. Policies must be established related to how transit amenities (e.g., seating, shelters, elevators, and signage) are distributed and how vehicles are assigned to depots and routes.
- **Collecting and reporting demographic data** (applies only to larger providers). Accurate demographic data are required to understand the extent to which Title VI–protected populations benefit from public transit services. Agencies must produce data on:
  - Demographic profiles of a provider's service area derived from decennial census or American Community Survey (ACS) data.
  - Travel patterns and ridership characteristics derived from passenger surveys. These data must be collected at least once every five years and can be generated using several different techniques.[3]
- **Monitoring transit service** (applies only to larger providers). Transit agencies must monitor compliance with their standards and policies at least once every three years. This requirement involves comparing the performance of "minority" and "non-minority" routes. Minority routes are classified as those where at least one-third of the revenue-miles overlap census blocks, block groups, or traffic analysis zones whose minority population share exceeds that of the service area. The circular notes that ridership data can also be used to understand whether a route is "minority" or not and notes two examples where census data could mislead. The goal of the monitoring is to "compare the level of service provided to predominantly minority areas with the level of service provided to predominantly non-minority areas to ensure the end result of policies and decision-making is equitable" [48, pp. IV–10]. Any observed disparities must be assessed and potentially mitigated.
- **Evaluating service and fare changes** (applies only to larger providers). Major service changes must be assessed for equity impacts by comparing the population affected by a change to that of the service area as a whole. All fare changes must also be assessed for equity impacts, with the analysis identifying whether proposed changes in cost bear more heavily on disadvantaged groups. Either census data or ridership data can be used for a service equity analysis, but only ridership data obtained from ridership surveys are effective for fare analyses since it is impossible to know, based on census data, what fare media people use.

[3] Surveys should also ask about riders' English proficiency and should be translated to other languages that are above the "Safe Harbor Threshold" consistent with the recipient's Language Access Plan outlined in its Title VI program.

While all FTA recipients and subrecipients must comply with Title VI regulations, FTA's specific Title VI Program requirement for fixed-route service providers addresses public involvement, data collection, and quantitative analysis. Recipients must complete and submit the Title VI Program to FTA for review by the regional civil rights officer every three years or on a different schedule upon direction from FTA. Prior to submitting the program, it must be approved by the agency's board of directors or equivalent body. Once submitted, FTA will either review and concur with the program or request additional information. Transit providers, states, metropolitan planning organizations, and other organizations receiving FTA funds undergo periodic formal oversight reviews that include Title VI compliance.

Other funding programs may have requirements separate from, but related to, those stemming from Title VI. For example, agencies applying for funds under Section 5310 (the Enhanced Mobility for Seniors and Individuals with Disabilities Program) must include candidate projects in a "public transit human services transportation plan" created with input from older adults, people with disabilities, and transportation service providers. Section 5310 funds are apportioned by a formula based on a state's or urbanized area's share of older adults and people with disabilities. They are intended to be used to meet the transportation needs of these two groups when the services already provided are judged to be insufficient, inappropriate, or unavailable. The National Center for Mobility Management, a consortium of charitable and transportation trade organizations funded through cooperative agreement with FTA, has generated a substantial knowledge base on human services transportation planning and interagency coordination. The National Aging and Disability Transportation Center, a national technical assistance center funded by FTA with guidance from the US Department of Health and Human Services' Administration for Community Living, also provides extensive support to communities in addressing needs. More information on both of these FTA-funded technical assistance centers is available on the FTA website: https://www.transit.dot.gov/ccam/resources/technical-assistance-supporting-communities.

FTA's Environmental Justice Circular 4703.1 covers environmental justice requirements and addresses how they overlap with Title VI requirements [49]. In particular, the Environmental Justice Circular clarifies that Tile VI's requirements are much broader than those enacted by Executive Order 12898. It states that sometimes environmental justice analysis requirements will overlap with those covered by Title VI, but that an analysis completed to comply with one set of concerns will not always stand in for the other. Examples of differences include:

- Title VI does not include low-income populations, while environmental justice requirements do.
- Title VI protected classes are based on race, color, and national origin, which may not equate to a minority community.
- Title VI applies to all activities undertaken by federal fund recipients, while environmental justice requirements only apply to those actions that may have a disproportionately high and adverse effect on relevant populations.

Title VI and Environmental Justice Requirements

"The overlap between the statutory obligation placed on Federal agencies under Title VI to ensure nondiscrimination in federally assisted programs administered by State and local entities, and the administrative directive to Federal agencies under the Executive Order to address disproportionate adverse impacts of Federal activities on minority and low-income populations explain why Title VI and environmental justice are often paired. The clear objective of the Executive Order and Presidential memorandum is to ensure that Federal agencies promote and enforce nondiscrimination as one way of achieving the overarching objective of environmental justice—fair distribution of the adverse impacts of, or burdens associated with, Federal programs, policies, and activities."

— FTA Circular 4702.1B, Ch. 1–7

Agencies should consult both circulars to ensure that they are properly incorporating both Title VI and environmental justice considerations into their planning and decision-making processes.

Assessing Transportation Equity Requirements

As demonstrated above, public transit agencies have a mandate to consider equity-related impacts but determining how they should best comply with equity-related goals can be challenging and is largely at the discretion of the local entities to determine what best fits the needs of their communities. Despite the requirements listed in Table 2-1 above, multiple areas of the regulatory and guidance documents related to transportation equity do not establish a one-size-fits-all approach. In general, various requirements and guidance for quantitative analysis provide wide latitude for communities to tailor to their locally defined goals and needs.

Accordingly, the results from such analyses range widely and can sometimes be uninformative [5, 6]. With respect to FTA's Title VI Circular, for example, the data collected to comply with the travel patterns and ridership characteristics requirements can be "collected at the time that such [passenger surveys] are routinely performed, such as customer satisfaction surveys and origin and destination surveys used to update travel demand models" [48, pp. IV–9]. But the nature of the data gleaned from origin destination surveys is typically much more detailed than that from customer satisfaction surveys. Origin destination surveys include information about the passenger's origin, destination, access/egress modes, and demographics. They are associated with the specific line used by the passenger and can assist in identifying the demographic characteristics of individual routes. Customer satisfaction surveys typically collect much less detailed information. Further, service equity analyses are known to produce different results when census or ridership data are used [4]. It is possible for a route to be classified as "minority" using census data, but "non-minority" when using ridership data, or vice versa [e.g., 51]. This inconsistency can unfortunately lead to an analyst choosing the data source needed to generate a desired outcome.

On the other hand, allowing analytical flexibility offers providers of all sizes, levels of technical expertise, and in varying geographic/demographic areas to tailor their approach to local needs rather than relying on a single method applied in all areas. Still, understanding the trade-offs, strengths, and weaknesses inherent in different data sources and analytical approaches can speak to their relative quality and value.

Public involvement, too, can be limited in effectiveness. In NCHRP Report 710, Aimen and Morris make a distinction between "public involvement" and "meaningful involvement" [52]. For those authors, public involvement emphasizes one-way communication and lacks formal mechanisms to close the loop between the feedback received and the decisions ultimately made. On the other hand, meaningful involvement builds in the potential for decisions to be shaped and otherwise affected by the feedback received. They claim that mere public involvement is more common than meaningful involvement but synthesize a number of approaches that could be used to reach the higher standard. FTA's EJ Circular 4703.1 outlines several non-traditional public involvement strategies and aspires to the higher standard of meaningful involvement [49, Ch. 3].

Karner and Marcantonio [36] argue further that meaningful involvement identifies and addresses the transportation *needs* of disadvantaged communities. This focus on needs is enshrined in the regulations governing FHWA and FTA's metropolitan and statewide transportation planning processes, specifically regarding "Interested parties, public involvement, and consultation" found in federal regulations (see 23 CFR § 450.316 (a)(1)(vii) and

23 CFR § 450.210 (a)(1)(viii)). It also undergirds the Section 5310 and related requirements to involve older adults and people with disabilities in the planning process (49 U.S.C. § 5310; 49 CFR § 37.137(c)). Understanding and responding to a community's needs clearly requires decisions that have been shaped by its input. Accordingly, FTA's Environmental Justice Circular 4703.1 states that the "full and fair participation by all potentially affected communities in the transportation decision-making process" is a guiding principle [49].

It is unlikely that traditional methods of public involvement will rise to the "meaningful involvement" standard proposed by Aimen and Morris [52]. Section 3 highlights equity-related practices at public transit agencies in the United States that push beyond public meetings and notice and comment procedures. These case summaries may be useful for agencies seeking to enhance equity-related outcomes in their communities.

Section 3

Transportation Equity Practices

This section summarizes best practices identified around the country that improve transit equity through public engagement and qualitative methods. It does not establish new guidance but can be used to inform researchers, practitioners, and policy makers on transit equity-related practices. The practices are organized into nine categories. Each represents a focus area where equity can be incorporated into the planning process to improve outcomes and ensure a fair distribution of the benefits and burdens of the public transit system and related planning processes. The equity practice categories are summarized in Table 3-1.

Table 3-1 *Summary of Equity-Related Practices Included in This Report*

Equity Practice	Description	Featured Transit Provider
Advisory committees	Committees are typically composed of appointed members or interested volunteers from the general public and advise the agency on equity-related matters. Transit agency decision-makers can receive valuable recommendations from committee discussions and related participation.	CapMetro MBTA Sound Transit TriMet
Fare policies	Reduced fare policies help ensure that riders have access to the transit services they need for daily mobility needs. Removing this barrier to transportation improves access to opportunities.	CapMetro MBTA TriMet
Intergovernmental partnerships	Equity-focused projects and initiatives are often joint efforts between transit agencies and other governments. These partnerships increase access to resources and staff and improve coordination, resulting in more impactful project outcomes.	Houston METRO MBTA rabbittransit
Leadership champions	Transit agency board members, agency leadership, and staff members can go above and beyond to champion equity issues in their cities and regions.	CapMetro Houston METRO MBTA
Advocacy partnerships	Transit agency actions can be influenced by nonprofit organizations that align with communities to advocate for or against policies, practices, and investments. Advocacy organizations help make the voices of disadvantaged communities heard.	Houston METRO MBTA
Metropolitan and statewide/ nonmetropolitan planning organizations	Regional planning organizations support public transit through policy and fiscal decisions. Transportation decisions at a regional scale affect local outcomes and MPOs are often an important forum for convening equity-related discussions.	Houston METRO MBTA

Table 3-1 (cont.) *Summary of Equity-Related Practices Included in This Report*

Equity Practice	Description	Featured Transit Provider
Capital planning	Capital planning affects the lived experience of using public transit through maintenance scheduling and the provision of rolling stock. The locations of transit hubs and maintenance facilities can affect the lived experiences of transit riders. It is especially relevant for people with disabilities who use public transit.	rabbittransit Sound Transit
Ride-hailing and microtransit	On-demand, flexibly routed service is an alternative to fixed-route transit. Underserved populations may benefit from this dynamic service, but its novelty means that more information and experience is needed before conclusions can be drawn.	CapMetro CUMTD Houston METRO rabbittransit
Creating an equity culture	Agencies can enact multiple organizational changes to advance equity. Chief among these is facilitating a culture of equity.	MBTA TriMet

Methods and Data

This review is based on a comprehensive study of transit agency documents focused on equity practices. The project team used their professional networks, knowledge of the public transit industry and related nonprofit advocacy organizations, and snowball sampling to identify transit agencies undertaking promising equity-related practices. A wide range of transit agency types were reviewed, from those operating single modes in rural areas to larger multimodal agencies in heavily urbanized regions. The project team reviewed publicly available documents for the following:

- Houston-Galveston Area Council (H-GAC)
- Sound Transit (Seattle, WA)
- LivableStreets Alliance (Boston, MA)
- TransitMatters (Boston, MA)
- City of York (York, PA)
- Eat Play Breathe York (York, PA)

In addition to reviewing publicly available documents, the project team conducted eight semi-structured interviews with public transit advocates and agency staff to better understand promising equity approaches and challenges [53]. Staff, decision-makers, and advocates were interviewed at the following:

- Metropolitan Transit Authority of Harris County (Houston METRO)
- LINK Houston (an equity-oriented nonprofit organization in Houston, TX)
- Champaign-Urbana Mass Transit District
- rabbittransit (a rural transit provider in southeast PA)

- Capital Metro (Austin, TX)
- Massachusetts Bay Transportation Authority (MBTA)
- Massachusetts Department of Transportation (MassDOT)
- Tri-County Metropolitan Transportation District of Oregon (TriMet)

Each interview began by providing an overview of the study and the team's definition of transportation equity, gathered from the literature:

> When we think about equity, we're specifically interested in how the benefits and burdens of transportation investments fall on different groups. Our concern is principally with those people and places that have been historically left out of planning and decision-making, including people of color, people with low income, older adults, youth, single parents, zero-vehicle households, and others.

Following this introduction, the team stepped through a series of questions, probing respondents to provide further details and allowing them to delve more deeply into issues and areas they felt important:

- Do you want to add anything or respond to our definition of equity?
- What are some examples of equity-related successes/challenges that your agency has been involved with?
- Does your agency have an advisory committee or other group that addresses equity-related issues?
- Do you conduct any analysis of transit rider survey (or related survey) data to understand the current or projected equity conditions/impacts?
- Do you partner with local jurisdictions to advance equity-related goals?
- Are there specific board members (or a single member) that you can identify as championing equity issues?
- Are there any active advocacy organizations in your region? Have you partnered with them on any efforts?
- Can you describe the relationship your agency has with your metropolitan planning organization? Have you engaged with them in the past to conduct planning and analysis?
- How do equity considerations play into your capital planning efforts?
- Are there other innovative service delivery, planning, public involvement, or other practices that your agency is engaged in that you'd like to share?

Interviews generally lasted one hour and were conducted using a teleconferencing platform. These were not recorded but extensive notes were taken rendering partial transcriptions. Interview results and findings from practice were synthesized to create relevant categories. Summarized below are the key findings from this mixed-method analytical strategy.

Advisory Committees

Transportation planning agencies at various levels of organization commonly establish advisory committees to provide more formal and regular channels for public input than can be achieved during public meetings or through public comments. Members of these committees can be appointed or nominated, but ideally they represent a constituency relevant to the purpose of the group. Establishing equity-oriented advisory committees with diverse and representative members can help transit agencies with related problem-solving and decision-making [37, 54]. Importantly, advisory committees provide an opportunity for public opinion to be organized and made meaningful to agency boards from the perspective of riders, stakeholders, and dedicated community leaders [55]. Of course, there is also a risk that an overreliance on advisory committees could gloss over the existence of smaller populations and crowd out their concerns. In the worst case, agencies can point to the existence of advisory committees to argue that enough participation has been achieved. This has long been of concern in the environmental justice advocacy community [42, 56, 57]. It is important to note that the context in which an advisory committee operates impacts how it is perceived as a vehicle for improving decision-making.

In this project's sample of public transit agencies, the advisory committees were widely employed and convened to address and advise on equity-related issues. Advisory committees are typically convened to address specific issues or to advise on project developments.

TriMet convenes a Transit Equity Advisory Committee (TEAC) whose goal is to provide guidance on investments, analyses, and strategies during monthly meetings and by advocating on behalf of transit-dependent riders [58]. The group focuses on improving equity, access, and inclusion and assists with community outreach and engagement [58]. More specifically, TEAC reviews TriMet's practices related to Title VI, Environmental Justice, planning, and operational investments [59]. The committee is composed of 17 stakeholders, including representatives of local advocacy organizations and community groups. TEAC has successfully advocated for reduced fares for low-income riders and has affected policy decisions and outcomes [59, 60]. The committee is working on an online equity dashboard to improve transparency about transit outcomes, safety, and efficiency with the public [61]. Related to these efforts, TEAC helped successfully implement a policy for decriminalizing fare evasion by changing the process from court procedures to administrative processes [59].

Physical accessibility—the extent to which users with disabilities can enter and use the transit system—is another focus of advisory committees. CapMetro has two committees that address equity and accessibility. The Access Advisory Committee is a diverse group including riders with different perspectives that advises on issues related to public transit and physical accessibility [62].

In 2013, the committee successfully advocated for a freeze on fare increases until a comprehensive survey was administered to understand the potential impacts on customers [63]. Similarly, Sound Transit has a Citizen Accessibility Advisory Committee composed of community members affected by physical accessibility issues that advises on issues related to aging populations, ADA compliance, accessibility, and mobility [64]. The committee has 15 diverse members including transit riders with disabilities, transit riders over the age of 65, caregivers of people with disabilities, and professionals within the field of disability and aging services [64]. The City of Seattle also has a Seattle Pedestrian Advisory Board that was created in 1997 with 11 total members appointed by the mayor and city council [65]. A special member seat is dedicated to a young adult appointment. The board has four tasks: (1) advise the mayor and city council on pedestrian impacts of proposed plans and projects; (2) contribute to the planning process related to pedestrian infrastructure; (3) promote improved pedestrian safety and accessibility; and (4) prepare an annual report of its work [65]. The board has successfully created a "Pedestrian Master Plan" with a 20-year horizon and implementation phases every three years [66]. As of October 2017, the plan has accomplished new and improved curb ramps and crossings, new sidewalk construction, improved safe routes to schools, and completed sidewalk repairs [67]. Members attending a meeting regarding walkability and cycling are shown in Figure 3-1.

Figure 3-1 *Seattle Pedestrian Advisory Board members shown at a meeting in January 2018*

Source: Ped Advisory Board [68]

Advisory committees also assist in understanding customer satisfaction and rider needs more generally. CapMetro's Customer Satisfaction Advisory Committee consists of nine regular transit riders appointed by the board of directors who advise on issues related to planning and operations [62]. In 2014, the committee successfully advocated for bus shelter improvements along pedestrian corridors in downtown Austin [69]. In late 2018, the committee focused on public engagement regarding CapMetro's microtransit pilots and on measures to increase ridership [70]. The Massachusetts Bay Transportation Authority has a rider oversight committee composed of riders, MBTA employees, and advocates that work to share the concerns of riders with the agency [71]. The committee discusses pedestrian accessibility, quality of service, and ongoing projects, and shares their perspectives and comments with the agency.

Large-scale projects or agency initiatives may have dedicated advisory committees to help oversee completion and project decisions. MBTA has an advisory committee overseeing a project to improve commuter rail service known as Rail Vision. Begun in 2018, the project's goal is for commuter rail users and other stakeholders to create eight alternative visions for the future of commuter rail transit in the region, similar to scenario planning [72]. The project's advisory committee is composed of a mix of local elected officials and professionals from the greater Boston region to offer diverse insights to MBTA leadership. The committee examines the potential costs, ridership, and feasibility measures of each alternative scenario in combination with weighing public input. As of October 2019, the advisory committee had hosted seven meetings to obtain feedback, concerns, and insights from the public and committee members [72]. In addition, the MBTA board approved the initial phase of the project in November 2019 to begin to electrify the rail system throughout the region. Sound Transit's system expansion planning process includes the formation of three advisory groups: an elected leadership group, a stakeholder group, and an interagency group [73]. The stakeholder group, composed of public transit riders, local businesses, community and advocacy organizations, and other members from the general public, helps Sound Transit identify preferred alternatives within the project. The stakeholder group also analyzes the project's impacts on the community, including short-term construction impacts and long-term tradeoffs within corridors [73]. Specifically, the stakeholder group helped inform the decision to undertake the West Seattle and Ballard Link Extensions project, providing new light rail transit connections between neighborhoods [74].

Advisory committees across the country advance equity-related objectives and they clearly can be effective at highlighting blind spots that may emerge when regular agency decision-making practices are followed. Their effectiveness is partly due to them bringing in people and voices likely to be underrepresented on decision-making boards and among planning staff [e.g., 75, 76]. Merely establishing an advisory committee can signal that an agency is concerned about equity issues but translating the committee outputs into action is the hallmark of a meaningful effort.

Fare Policies

Transit agencies can modify their fare policies to reduce the financial burden of travel costs. By targeting specific demographic groups, including low-income people, older adults, people with disabilities, and youth, agencies can alleviate barriers to access for the populations most in need of public transit.

TriMet's feedback from public participation in recent years has focused on fare affordability for transit dependent populations. In 2018, TriMet implemented a means-tested reduced fare program for residents with earnings that place them below twice the federal poverty level [77]. Since its launch in July 2018, more than 10,000 riders have applied and qualified for the fare reduction, which amounts to discounts of 50% on single rides and day passes and 72% off monthly passes [77]. The agency achieved high enrollment through extensive public outreach and events to engage with potential qualified users. In total, 54 enrollment events were held in the Portland region to help low-income riders take advantage of the program, as shown in Figure 3-2 [77].

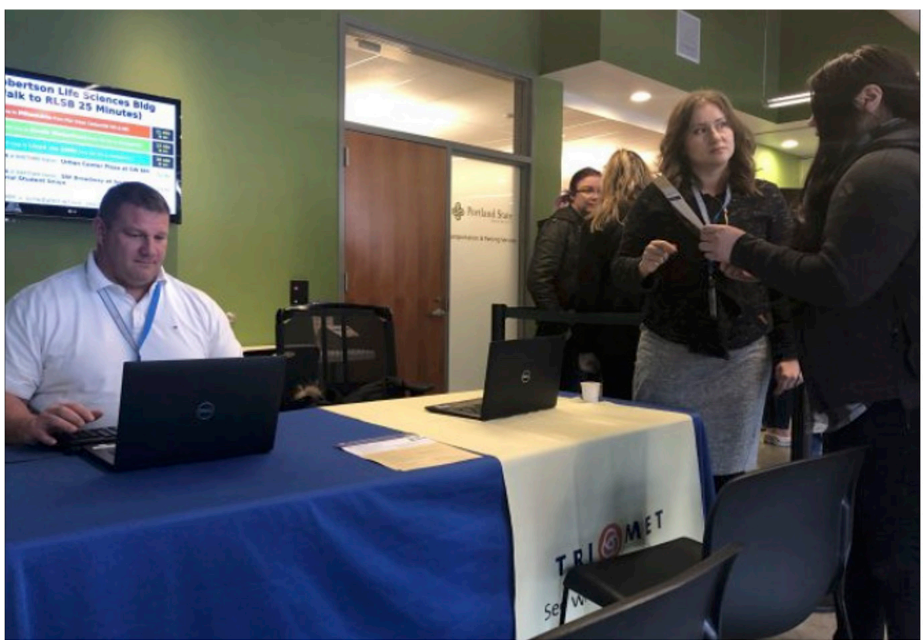


Figure 3-2 *Enrollment event held at Portland State University for TriMet's low-income fare reduction program*
Source: York [77]

MBTA piloted and implemented a youth pass to bridge the gap in access to transit for low-income young adults ages 19–26 [78]. The youth pass, providing reduced fares in collaboration with local cities and towns, was marketed through advocacy skits and performances to advertise the concept in appealing ways to young adults. The product has resulted in increased travel, better outcomes, and an increase in overall mobility [78].

CapMetro offers reduced fare cards for senior citizens, Medicare card holders, active-duty military personnel, and riders with disabilities to increase access to opportunities through public transit.[4] In addition, youth under the age of 18 ride CapMetro's transit services at no cost with valid student identification. These programs work to relieve financial stress that can be associated with riding public transit.

Intergovernmental Partnerships

Support from other governments, including cities, counties, states, and special districts, can help transit agencies achieve transportation equity. Planning and public involvement can be enhanced through cooperation and combining resources and staff from multiple organizations. In the simplest case, partnering with a city or county government can provide a transit agency with insights about local travel needs that they might not otherwise have access to. Many of the agencies investigated for this research regularly partnered with other governments.

Rabbittransit has successfully partnered with the City of York, Eat Play Breathe York, and a young professional's group to improve the quality of life for transit dependent families. They jointly implemented transit stop improvements that included playground panels and tic-tac-toe to better serve the demographics of that stop's users [79]. This project encourages children to be more active during their daily travel, improving their health and overall well-being [80]. Rabbittransit has observed that these new station amenities have drawn riders from nearby stops. This project also helped support a food accessibility goal, as it was implemented at a stop located closest to a local farmer's market [79].

Also focused on improving accessibility for its residents through collaboration with local jurisdictions, Houston METRO performed corridor improvement projects with the City of Houston in support of a bike plan adopted in March 2017. METRO is involved with street-level implementation of the bikeways and related pedestrian improvements [81]. This cooperation will lead to more comprehensive outcomes for the corridors, increasing multimodal opportunities for residents.

MBTA has developed an innovative approach to public participation in its equity and Title VI analysis process that includes a collaboration with MassDOT. The Massachusetts Office of Diversity and Civil Rights Title VI Unit, in collaboration with MassDOT's planning department, developed Engage, an online public

[4] https://capmetro.org/rfid/.

engagement tool [82]. This tool facilitates on-demand access to data about communities during public meetings, including languages spoken, local community organizations, accessible meeting locations, bus stops, routes, stations, and local transit projects, as shown in Figure 3-3 [82]. MBTA uses Engage to better connect with residents during the public participation process by using local data. Engage is also used as supporting evidence for the MBTA when other stakeholders ask about the thinking behind planning decisions [83].

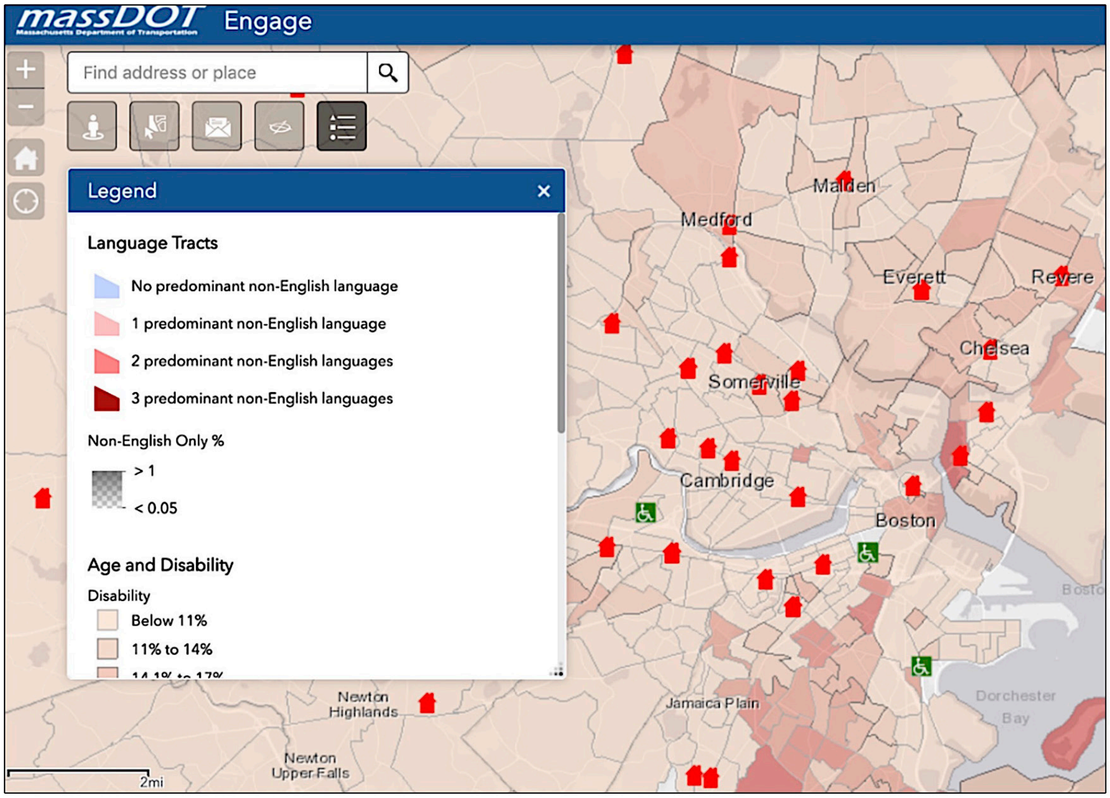


Figure 3-3 *MassDOT's Engage tool, showing accessible meeting locations and proportion of people with disabilities*

Source: MassDOT [84]

Partnerships with county agencies can help inform public transit expansion plans. For example, CapMetro collaborated with Travis County on an effort that necessitated an expansion of the agency's service area [85]. The plan allowed CapMetro to negotiate the logistics and funding required to expand service into previously unincorporated or unserved regions of the county, known as transit gap zones (Figure 3-4) [85, 86]. The two jurisdictions work together to provide meaningful services to the more rural areas, including mobility on demand, community-based services, and service extension projects [86].

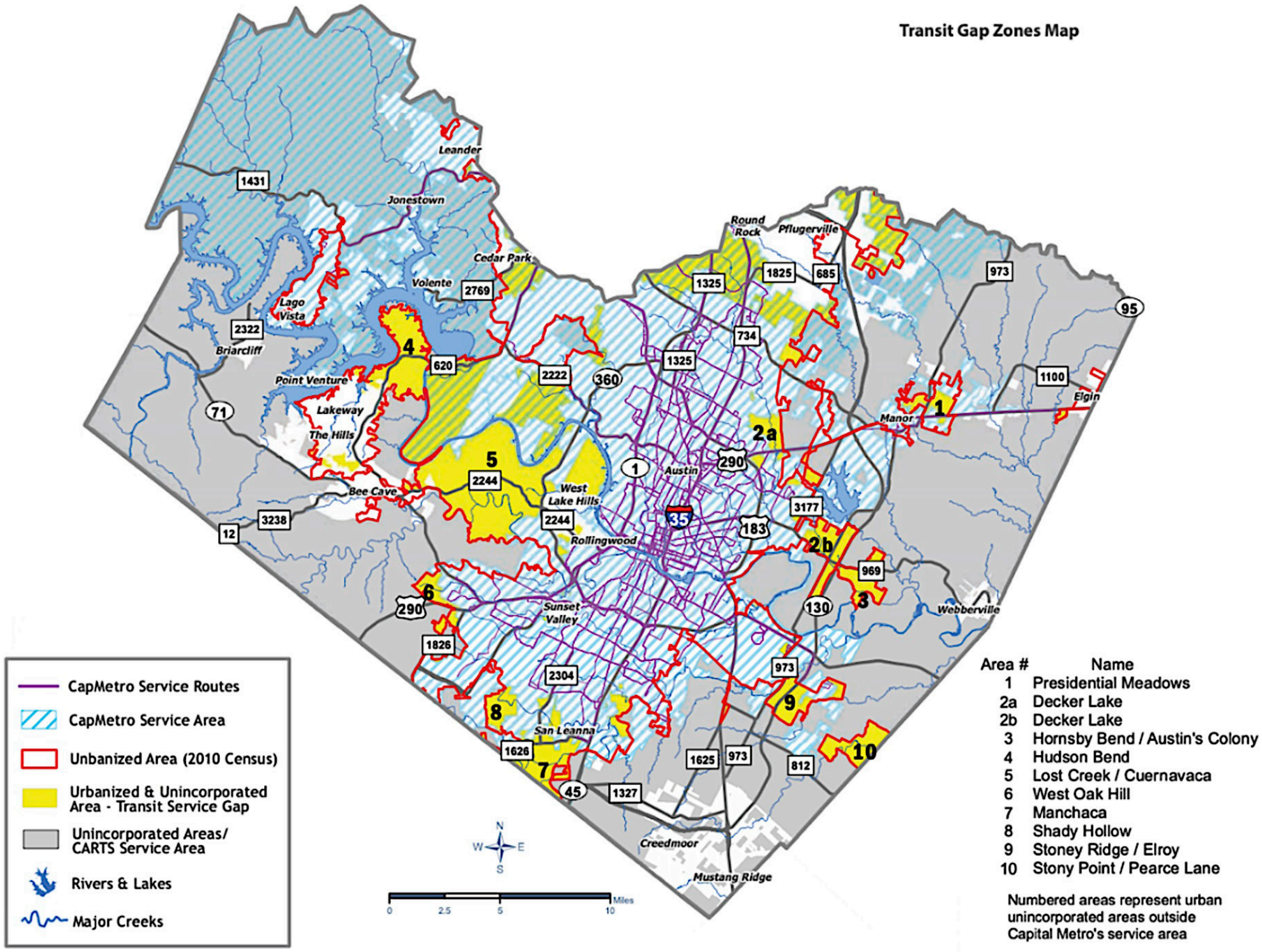


Figure 3-4 *Transit gap zones, shown in yellow, addressed by a partnership between CapMetro and Travis County*

Source: Travis County [86]

Intergovernmental partnerships allow transit agencies to undertake initiatives that they would be unlikely to pursue on their own. These involve large-scale efforts that span across regions and metropolitan areas as well as smaller measures that target specific areas of high needs, such as a specific transit stop.

Leadership Champions

Sometimes an individual board member, decision-maker, or agency staff member can advance equity outcomes by personally championing specific issues. These individuals seek to elevate values and objectives related to transportation equity, and their public actions speak to these efforts. Equity champions are most commonly found on transit agency boards—board members are often political appointees who enjoy substantial autonomy and are thus able to lift up specific issues they consider pertinent. Because most boards contain a relatively small number of participants, a single member can have an outsized influence on shaping equity in a region. Champions can provide a high level of oversight and can demand accountability to ensure that equity-oriented plans and policies are implemented and enforced. Table 3-2 lists several examples of board champions found in the research team's review of agency practices.

Table 3-2 *Transit Agency Board Members and Key Initiatives Related to Equity Promotion*

Agency	Board Member	Initiative	Links
Houston METRO	Lex Frieden	ADA compliance and physical accessibility	Houston disability activist Lex Frieden, Metro investing in sidewalks so elderly, disabled can get to bus stops
Houston METRO	Christof Spieler	System Reimagining and rider advocacy	Mapping time, New rail lines and bus routes mark a turning point for METRO, Why the people in charge of transit systems should be required to actually ride transit
CapMetro	Ann Kitchen	Access to opportunities and system environmental performance	Capital Metro takes major steps toward all-electric fleet, Kids ride free program now permanent for all Capital Metro bus, rail services in Central Texas
MBTA	Monica Tibbits-Nutt	Community advocacy and transit affordability	Baker, T board members at odds on revenue strategy, Advocates call for reduced MBTA fares for low-income riders

Houston METRO has important leadership champions focused on equity and accessibility. Lex Frieden is a board member and prominent advocate for people with disabilities and older adults. He was instrumental in the development of the Americans with Disabilities Act of 1990 (ADA), and he continues to focus on contemporary outcomes of ADA initiatives in urban planning [87]. Frieden aims to make public services accessible and equitable for Americans of all abilities and circumstances. He led efforts to make all 9,000 METRO transit stops ADA accessible, including surrounding sidewalk infrastructure [87]. As of February 2019, METRO had begun the construction process for sidewalk investments and improvements near bus stops [88].

Previous Houston METRO board member Christof Spieler championed the agency's network redesign, named System Reimagining. Spieler is an avid public transit user and used his personal ridership experience to advocate for increased fixed-route frequency. He was able to advocate for the high-frequency grid network that was successfully implemented in 2015 [89]. System Reimagining in Houston was the first of many bus network redesign efforts undertaken throughout the United States and around the world.

CapMetro's Ann Kitchen is a board member who also serves as a city councilor, Capital Area Metropolitan Planning Organization board member, and chair of Austin's Mobility Committee. Focused on access to opportunities and health care services, she helped champion the CapMetro Kids Ride Free program in December 2018, which allows children under 19 to ride free on all services [90]. She is also heavily involved with testing and implementing battery electric buses by collaborating with Austin Energy and stressing the importance of system-wide change [91]. A shift to zero-emission vehicles would have positive environmental benefits for multiple communities throughout Austin.

MBTA's Monica Tibbits-Nutt, vice-chair of the board, advocates for youth engagement and community advocacy. She helped champion the fare pass for youth riders, vocalizing to the board her beliefs and concerns [83]. Tibbits-Nutt is also focused on conducting a feasibility study for a low-income reduced fare pass [92].

Advocacy Partnerships

Transportation advocacy organizations aim to improve the quality of life for residents dependent on public transit and may act in support of or opposition to agency decisions [e.g., 54]. In part by consolidating and focusing residents' power, they provide a valuable platform for connecting residents' stated needs and concerns into more formal public involvement channels undertaken within the planning process. Multiple agencies regularly partner with advocacy organizations, even though the relationships are sometimes contentious, recognizing that both parties have an interest in delivering more equitable outcomes.

LINK Houston, a nonprofit advocacy organization focused on transportation equity and related issues, is highly invested in ensuring equitable service and public engagement opportunities in the Houston metropolitan region. LINK works to connect community members to the planning process and to policy makers throughout Houston since residents are often unaware of, or feel uninformed about, public meetings and other participation opportunities. For example, LINK aims to inform communities about these opportunities through Houston METRO and help them frame their needs and recommendations in meaningful ways that METRO leadership will better respond to [81].

During METRO's ongoing long-range planning process entitled METRONext, LINK brought community members to METRO board meetings so that their voices could be heard. In January 2019, LINK helped community members with disabilities engage with METRO to identify and prioritize accessibility improvements throughout the transit system [81].

LINK Houston published a report regarding the state of transit equity in the region in 2018 and updated the report in 2020. The reports used a Transportation Equity Demand Index (TEDI) to aggregate 15 indicators affecting transit equity across Houston [93]. These indicators, listed in Figure 3-5, highlight areas where the need for transit based on demographics, transport disadvantage, and neighborhood context are particularly high. The goal of the index is to identify disadvantaged communities that have the greatest need for transit to improve their quality of life [93]. The report ultimately recommends that public transit in the region must become more frequent, available, reliable, and accessible to improve equity.

CATEGORY	INDICATOR	FORMAT	GEOGRAPHY	YEAR	UPDATED	SOURCE
Fundamental Demographic Demand	**Households in Poverty**	Percent	Block Group	2014–2018	Annual	U.S. Census Bureau, American Community Survey
	Single Parent Female Headed Households with Children Under Age 18	Percent	Block Group	2014–2018	Annual	U.S. Census Bureau, American Community Survey
	Households with One or More Persons with a Disability	Percent	Block Group	2014–2018	Annual	U.S. Census Bureau, American Community Survey
	Homes of Workers with Jobs Paying Less Than $15,000 Annually	Number	Block	2017	Annual	U.S. Census Bureau, Longitudinal Employer-Household Dynamics
	Work Sites of Workers with Jobs Paying Less Than $15,000 Annually	Number	Block	2017	Annual	U.S. Census Bureau, Longitudinal Employer-Household Dynamics
Likely Higher Transit Use *(i.e., propensity, latent demand, or induced demand)*	**People of Color Population**	Percent	Block Group	2014–2018	Annual	U.S. Census Bureau, American Community Survey
	Zero Vehicle Available Households	Percent	Block Group	2014–2018	Annual	U.S. Census Bureau, American Community Survey
	Workers Commuting by Transit	Percent	Block Group	2014–2018	Annual	U.S. Census Bureau, American Community Survey
	Homes of Workers with High School Education or Less	Number	Block	2017	Annual	U.S. Census Bureau, Longitudinal Employer-Household Dynamics
	Work Sites of Workers with High School Education or Less	Number	Block	2017	Annual	U.S. Census Bureau, Longitudinal Employer-Household Dynamics
Human and Built Environment Suitability	**Population Density**	Number	Block Group	2014–2018	Annual	U.S. Census Bureau, American Community Survey
	Household Density	Number	Block Group	2014–2018	Annual	U.S. Census Bureau, American Community Survey
	Street Intersection Density	Number	Block Group	2018	Annual?	Center for Neighborhood Technology
	Average Block Perimeter–Feet	Number	Block Group	2018	Annual?	Center for Neighborhood Technology
	Compact Neighborhood Score	Number	Block Group	2018	Annual?	Center for Neighborhood Technology

Figure 3-5 *LINK Houston TEDI indicators*

Source: LINK Houston [93]

LINK Houston has also worked with Houston's mayor to analyze and identify the most dangerous intersections in the city using data on crash rates, pedestrian and bicyclist safety, and risk to prioritize intersections [94]. LINK Houston was able to successfully advocate for the city to focus on improving pedestrian safety, and a Pedestrian Safety Task Force is planned [95]. The mayor also plans to appoint a Street Safety Coordinator to lead the new initiatives [96].

Two primary advocacy partnerships improve transit conditions for rabbittransit riders. The first is the Transportation Partnership on Mobility (TPOM), a forum for receiving feedback from transit users and advocates that meets once a month. The meeting location rotates between the rabbittransit counties [79]. Anyone is welcome to attend TPOM meetings and participants are drawn from representatives of various transportation-disadvantaged populations including older adults, people with disabilities, and veterans. Rabbittransit also partners with 3P-Ride, a nonprofit focused on inclusive planning. A key initiative of the nonprofit is called Live Fully Travel Safely, which provides resources for older adults seeking to transition from driving personal vehicles to using rabbittransit services [79].

The greater Boston community is heavily invested in transportation equity and quality service. TransitMatters is a prominent transportation advocacy organization focused on several initiatives to improve public transit. Their substantive goals include overnight transit service, fair fares, regional rail, bus network improvements, mobility hubs, transit route connectors, and data-driven transparency and accountability at MBTA [97]. TransitMatters successfully built a coalition of riders to advocate for the Red-Blue connector, a long walkway to connect two heavy rail lines, leading to its inclusion in MassDOT's Focus40 plan after previously being omitted [97]. The co-founders of TransitMatters have described the organization's mission as follows: "we have made it a cornerstone of our advocacy mission to identify cost-effective approaches to service improvements that are gleaned from national and global examples and best practices, and that will have maximum benefit to the public" [98].

MBTA partnered with LivableStreets Alliance, a Boston-based transportation equity nonprofit, to initiate bus lane pilots in 2016 and 2018. The effort reduced morning commute times for riders [99]. In 2016, the city of Everett, MA, replaced street parking with a bus lane after riders were interviewed and a need for better service to downtown Boston was identified [100]. In 2018, the city of Boston converted 1.2 miles of Washington Street into a bus lane pilot after long and unreliable commute times were reported along the route [101]. Within a month, the success of the lane led to its permanent status in the transit network.

Metropolitan Planning Organization (MPO) Planning

Metropolitan planning organizations (MPOs) and regional transportation planning organizations (RTPOs) coordinate transportation decision-making across multiple jurisdictions. MPOs are required by federal law to produce metropolitan transportation plans (MTPs), transportation improvement programs (TIPs), and unified planning work programs that budget funds for activities such as public involvement and data collection and analysis. MPOs are required in urbanized areas exceeding 50,000 in population, while states have the option to designate RTPOs in nonmetropolitan areas. The examples below focus on MPO collaboration, but similar efforts could be undertaken with other relevant planning agencies.

Public transit agencies seeking to use federal funds must partner with their MPO to ensure relevant projects appear on the TIP. Because MPOs are frequently the leading entity with any type of regional jurisdiction, they are often an important venue for multi-jurisdictional conversations related to issues that cross municipal and regional boundaries such as transportation, housing affordability, gentrification/displacement, air pollution, water quality, and education. MPOs must also comply with federal planning laws and regulations including Title VI regulations and environmental justice guidelines. If they are a direct recipient of FTA funds, they must submit their own Title VI program according to the requirements of FTA's Title VI Circular. This compliance has made MPOs a favored level of governance for seeking equity outcomes [37]. On equity-related matters, collaborations between MPOs and public transit agencies are vital.

The Houston-Galveston Area Council (H-GAC), the MPO in Houston's metropolitan region, addresses environmental justice requirements by conducting public outreach and engagement, identifying proposed benefits and burdens to environmental justice communities, and promoting an "equitable distribution of benefits" [102]. One example of their approach involves surveying attendees of environmental justice-oriented public meetings during the preparation of their 2040 regional transportation plan. The survey was completed by 170 participants and helped the council better understand the impacts of various transportation investment options on environmental justice communities [102].

H-GAC has noted that the public engagement strategy for environmental justice communities during the 2040 regional transportation planning process consistently produced high turnout, with the number of attendees at public meetings often exceeding 400 [102]. Through collaboration with the Houston Housing Authority, H-GAC was able to gather input from transportation-disadvantaged residents. In addition, young adults and students provided input through open house meetings in a local university student center [102]. Meeting attendees stressed public transit investments as a priority in the region and helped highlight the impacts of local transit decisions.

The Houston-Galveston Area Council collaborates with Houston METRO to provide funding for accessibility improvements. In addition, costs are split between the two governing bodies for research projects and data collection [81]. This arrangement provides both entities with better models and indicators of future conditions and outcomes.

MBTA collaborates with 13 MPOs, including 10 technical and 3 rural planning agencies, for more consistent and accurate data projections and forecasting [78]. Land use and demographic data from the MPOs is used in agency analysis and modeling, rather than collecting their own data, because of its comprehensiveness [78]. MBTA also works with their MPOs to analyze the local and large-scale impacts of transit routes on the environment and local communities [83]. The geolocation of the costs and benefits from public transit have been studied [83].

Capital Planning

Public transit capital planning involves setting priorities for acquiring and maintaining capital assets including rolling stock, buildings, and maintenance equipment. Capital planning has not historically been an area permeated by equity concerns, but several of the agencies sampled here demonstrate promising examples of equitable capital planning.

MBTA conducted a multimodal equity analysis for their capital improvement program to better understand the impacts of data, decisions, and analytical choices on equity outcomes [83]. The process revealed a need for flexibility, including buffers that vary by project type to determine impact. It also revealed gaps to address in the future, including digitizing all projects for geographic analysis and ensuring that all relevant funding was included in the program (including that from municipal sources).[5]

Rabbittransit focused on paratransit vehicles in their capital planning. Rider feedback brought to their attention the potential shortcomings of various vehicle design characteristics [79]. The agency completed an evaluation in association with the Transportation Partnership on Mobility and became aware of issues with existing vehicles including interior noise and poor floor design. Rabbittransit responded by retrofitting paratransit vehicles with sound-absorbing materials and directly addressing rider concerns [79].

As a transit-supportive example, the Seattle Department of Transportation conducted a sidewalk assessment in 2017 to identify and prioritize repairs in collaboration with the Seattle Pedestrian Advisory Board [103]. Pedestrian infrastructure provides an essential link between people and public transit. All existing sidewalk segments were surveyed, and the results were used to inform future investments and improve the physical accessibility of pedestrian infrastructure [103]. A result of the project is an online accessible route planner dedicated to supplying the public with physical accessibility information and transit access for residents with mobility challenges [104].

[5] https://www.mass.gov/files/documents/2019/06/28/dot-CIP_JointBoard_061719.pdf.

Ride-hailing and Microtransit

Ride-hailing has the potential to facilitate public transit use by connecting riders to line-haul service [105, 106]. It involves using smartphone apps to summon a vehicle that provides point-to-point travel for a fee. When applied to or operated by public transit agencies, the word microtransit is sometimes used to refer to this service. Shared mobility refers more broadly to vehicles of any mode that are shared [105]. These vehicles could include, for example, cars, vans, bicycles, or e-scooters.

In principle, fixed-route service should be sufficient to serve most of the transit needs in a region, but trade-offs between coverage and ridership lead to potential transit riders being unable to access services [107, 108]. Microtransit can provide on-demand transportation to groups of passengers using dynamic routing and scheduling. Transit agencies can use microtransit to improve equity in their service area by increasing both coverage and ridership. Microtransit may then remove barriers to accessing public transit, including spatial, temporal, economic, physiological, and social challenges [107]. Several of the sampled agencies have experimented with microtransit.

CapMetro launched two microtransit pilot projects in 2018 after implementing Cap Remap, a major bus network redesign. The first, MetroLink, was launched through an outside contractor to provide on-demand service to areas underserved after Cap Remap [85]. This pilot project was soon replaced by a more permanent microtransit service operated directly by CapMetro. This change occurred in response to customer experience feedback as well as changes in ridership and demand patterns [109]. Pickup, run by CapMetro vehicles and staff, has been more successful. Four service zones are offered in areas affected by Cap Remap (Figure 3-6) [85]. Users can request pickup and drop-off locations that are both situated entirely within a single zone. Rides are offered by telephone or mobile application and cost the same as regular bus fare, approximately $1.25. Pickup has steadily increased in ridership, and the average response time is approximately 8.5 minutes [85].

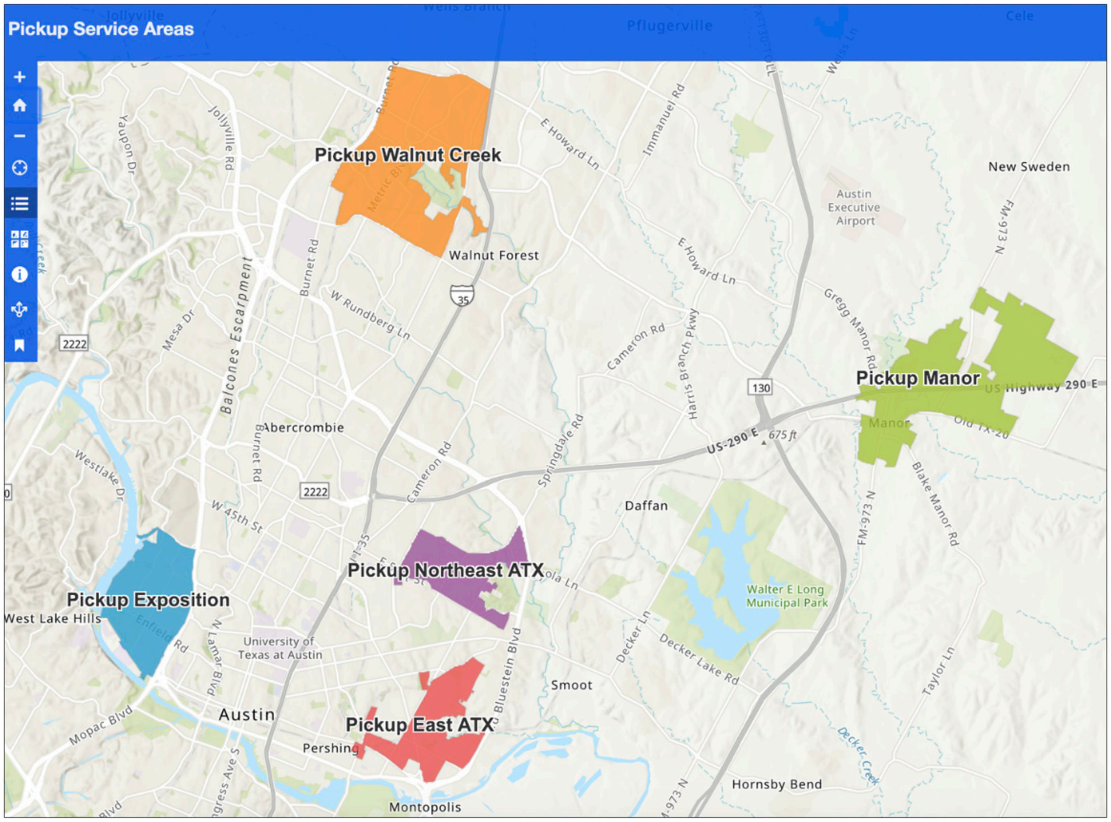


Figure 3-6 *CapMetro Pickup service areas in Austin, TX*
Source: CapMetro [110]

Houston METRO has an on-demand microtransit project called the Community Connector that serves an area in northwest Houston. Different from traditional on-demand services, the Community Connector operates as a complement to fixed-route service in the community [111]. METRO emphasizes that pedestrian infrastructure problems, such as missing sidewalks, narrow streets, and ditches in the roadway, were highlighted by customers as reasons they prefer the door-to-door Community Connector program over traditional fixed-route service [112]. Both the fixed-route and on-demand service continue to operate simultaneously as of mid-2021.

The Champaign-Urbana Mass Transit District launched an on-demand service pilot in 2019 serving as a late-night ride option at the university [113]. The service uses technology called Routematch that is operated by agency employees using an onboard tablet system [113]. The goal is to expand the project to become a weekday option in regions of Champaign underserved by fixed-route service. Transit disadvantaged communities would be the target customer base for the on-demand service, with intentions of improving transportation equity for areas difficult to serve by fixed-route transit.

Microtransit provides another opportunity for transit agencies to offer service to residents not well served by fixed-route networks. But unbanked populations (i.e., people not served by a bank or similar financial institution), as well as residents without smartphones, may experience challenges when using the services. To alleviate these concerns, CapMetro has made their microtransit service available through calls to a traditional call center as well as through a smartphone app [85]. Wheelchair accessibility for microtransit pilots continues to be of concern, especially due to the nature of curb-to-curb services. Potential riders must be able to traverse the sidewalk and driveways leading to the vehicle at their origin and final destination. However, all CapMetro's Pickup vehicles are ADA accessible and can accommodate wheelchair users [114].

Creating an Equity Culture

Diversity, equity, and inclusion initiatives are commonly pursued by organizations of all types. But these three concepts are not the same, and efforts often focus on diversifying—increasing the number of staff or participants with marginalized identities—rather than inclusion, which requires giving individuals resources to accomplish goals and the power to influence decisions [115, 116]. In principle, a more diverse staff that is truly included within an organization can better reflect the perspectives and needs of all communities, rather than just those that traditionally hold positions of power [115]. Toole et al. [116] describe multiple organizational changes that transportation agencies can pursue to achieve equity through diversity and inclusion initiatives. Chief among these changes is facilitating a culture of equity.

Two agencies implemented this principle such that equity serves as the foundation of all decision-making: TriMet and MBTA. TriMet weaves equity-related goals and practices throughout their agency to shift focuses from equity analyses to adopting an equity culture. The agency's Department of Equity, Inclusion, and Community Affairs promotes this culture using many different approaches. For example, the department helped TriMet set and address goals related to civil rights, diverse and inclusive contracting, and Title VI [60]. Similarly, MBTA strives to incorporate equity into as many performance measures and practices as possible. They aim to surpass minimum Title VI requirements to reach equity standards they believe are meaningful for their communities. Key to supporting these goals are their hiring practices, which value expertise and interest in transportation equity and justice [78].

In 2017, MBTA adopted a tool to measure system costs and benefits to understand route performance. Ridership characteristics, transit-dependent ridership, and the value of the route to the network are identified by the tool, leading to comparisons between and along routes [117]. Route strengths and weaknesses are highlighted by the tool, offering prioritization and guidance for the agency in improving transportation equity.

TriMet used feedback from public transit riders to improve fare affordability. In 2018, TriMet implemented a means-tested reduced fare program for riders whose earnings placed them twice below the federal poverty level [118]. By reducing the cost of transit fares, the system is more affordable for communities dependent on transit for their mobility. Through extensive outreach programs and events, enrollment has been maximized, with more than 10,000 riders enrolled in the program [118].

Conclusions

Transportation equity is a policy and planning goal that is enshrined in federal law, regulations, executive orders, and agency guidance. While most agencies would agree that achieving transportation equity is important, there are widely varying approaches toward its achievement and few systematic reviews that seek to understand just how effective different measures are at advancing equity goals.

Agencies regularly conduct quantitative spatial analyses to comply with equity requirements, but these seldom move the needle on key equity outcomes on their own. Similarly, according to research with underserved populations, commonly employed public engagement approaches are viewed as unsatisfying across many applications and rarely lead to changes in decisions already made [36].

On the other hand, communities can advance transportation equity goals through multiple practices aimed at improving meaningful public engagement or otherwise enhancing coordination and collaboration across decision-making entities. Innovative and collaborative equity practices help to illuminate and address the transportation needs of underserved populations, as demonstrated in the results presented above.

This section involved analyzing agency documents and conducting interviews with staff members to highlight transportation equity best practices relevant to public transit agencies. Promising practices related to advisory committees, fare policies, intergovernmental partnerships, leadership champions, and other planning activities were highlighted. Each of these moves beyond traditional public meetings to identify and address the needs of transportation disadvantaged populations. Technology and data are also crucial to achieving transportation equity and offer innovative ways for agencies to provide and evaluate service. The equity practices reported here provide a toolbox of methods for transit agencies and their partners to develop and apply in conjunction with other quantitative approaches.

Section 4

Spatial Analysis and Step-by-Step Examples

Transportation agencies regularly engage in performance measurement to understand the outcomes they can expect from their projects, programs, plans, and policies. Understanding performance is important to inform agency decision-making as well as public perceptions of impacts. Rigorous analysis of the benefits and burdens of transportation decisions, informed by meaningful data and methods, can supplement the equity approaches highlighted in Section 3 and go a long way toward ensuring that benefits and burdens are equitably distributed across population groups and across space. These types of analyses form the cornerstone of many "transportation equity" and environmental justice assessments conducted by transportation agencies across geographic scales [6].

This section describes five accessibility measures that agencies can use to quantify the benefits and burdens of public transit service changes. Ideally, any agency seeking to use the measures will recognize the value of deeply considering the knowledge and perspectives gleaned from local partners—especially those who have historically been denied access to the transportation planning process or other groups with unmet transportation needs. Gaining access to such knowledge and perspectives requires a sustained effort aimed at building trust and goodwill between an agency, community-based organizations, and local residents. With a trusting relationship in place, local partners can set the context for an equity analysis and help to ensure that the results are meaningful, comprehensible, and actionable.

Following is a brief overview of the accessibility measurement literature[6] before the five measures are summarized. Each of the measures is demonstrated using an example service change scenario drawn from Houston METRO's bus network redesign undertaken in 2015.

Accessibility Measurement

Handy and Niemeier describe accessibility as "the potential for interaction, both social and economic" [15, p. 1175]. Other definitions refer to the "ease" with which opportunities or destinations can be reached [119, 120]. Regardless of the specific definition used, an analyst always has to make a number of decisions about the components of accessibility to include. Geurs and van Wee [16] delineate four such components:

[6] See Appendix A for a more complete literature review.

1) Land use, reflecting characteristics of both origins and destinations
2) Transportation, reflecting the generalized costs of travel
3) Temporal constraints on individual travel (e.g., store hours or mandatory activity locations)
4) Individual factors, including ability, need, travel time budgets, and mode availability

Not all accessibility measures incorporate all four. Kwan [17] compared various “integral” measures of accessibility that consider only land use and transportation elements to “space-time” measures that additionally consider temporal constraints and individual factors:

- Integral measures are calculated based on distance from a single reference location (e.g., place of residence) while space-time measures further consider how an individual’s daily activity patterns affect the destinations they can reach. Cumulative opportunities measures are typically of the integral type, since they are calculated for a geographic unit (e.g., census tracts or block groups) and use idealized travel time thresholds rather than information about how people travel.
- Space-time measures are constructed piecewise, using knowledge of activity patterns and activity locations to construct an area over which destinations can be reached.

Different agencies face different decision contexts and not every accessibility measure will be applicable in every situation. Classifying and comparing accessibility measures can help to understand their inherent strengths and limitations and identify those measures that might be appropriate or inappropriate for certain use cases.

Figure 4-1 depicts one classification scheme that can be used to illuminate different aspects of accessibility. The figure summarizes five types of measures, together with data that can be used to calculate them, arranged along two axes. The horizontal axis places measures according to the extent to which travel demand is explicitly considered by the measure. It ranges from “demand agnostic” measures that include no consideration of travel patterns to “demand aware” measures that consider the richness of transportation choices and conditions across trip purpose, mode, and space, to understand how accessibility is affected by daily movement. The vertical axis places measures based on whether they consider accessibility to be related to opportunities themselves or to how individuals realize or take advantage of those opportunities. The “user benefits” label in Figure 4-1 refers to measures relating to changes in travel outcomes experienced by individual system users as opposed to “user opportunities” measures that assess more aggregated outcomes.

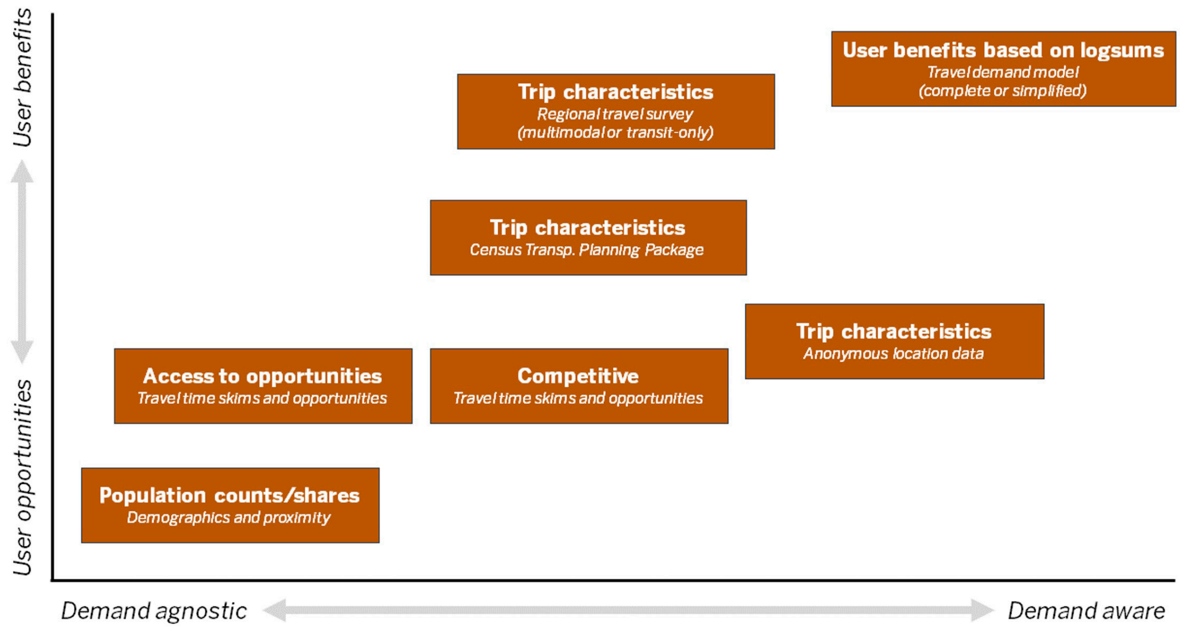


Figure 4-1 *Seven possible accessibility measures (bold) and data sources (italics) organized by the extent to which they incorporate travel demand (x-axis) and their representation of benefits (y-axis)*

Note: "Trip characteristics" appears three times to demonstrate the effect of differing data sources on the classification.

Population Counts and/or Shares

The simplest accessibility measures are based solely on proximity to transportation infrastructure and assess population counts and/or shares of the population in different groups that enjoy physical proximity (e.g., the share of the population in a region within 1/4 mile of a bus stop). They do not consider travel demand or destination opportunities and understand infrastructure proximity to be the primary "opportunity" provided by the transportation system [e.g., 121–124].

Access to Opportunities

Measures of access to opportunities tally the number of opportunities (e.g., jobs, grocery stores, high schools) that can be reached from all origin locations within a travel time threshold. A common access to opportunities measure might quantify the number of jobs accessible within a 45-minute trip. These measures consider travel demand in some sense because they rely on aggregate travel times. If travel is by automobile, travel times will depend on levels of congestion. Such measures generally do not include information about where people need/desire to go [e.g., 125–127]. This property means that accessibility for a particular mode might have little relationship with that mode's actual use.

Competitive Measures

Competitive measures integrate information across modes to understand how competition from other residents and between employers reduces the attractiveness of specific opportunities (such as employment), that can only be consumed by one person [e.g., 128–133]. Instead of simply tallying the number of opportunities accessible within a travel time threshold, competitive measures divide the number of reachable opportunities by the number of other people able to reach them. The resultant measure can highlight the relative accessibility benefit of more peripheral regional locations compared to others more centrally located.

Trip Characteristics

Unlike the prior three measures, trip characteristics reflect the performance of trips that people actually make. A commonly used example would be average regional commute time. Calculating trip characteristics requires some information on travel behavior. Figure 4-1 considers three different sources of behavioral data, with different implications for the measure's demand awareness and opportunity/benefit orientation. Anonymous location data derived from cellphone traces and other sources (e.g., travel times by mode, time spent in congestion, waiting time for public transit) can incorporate the richness of daily travel and are fully demand aware, but they are ignorant of demographics—so understanding how individual travelers experience accessibility is not possible.

Trip characteristics calculated using the Census Transportation Planning Package (CTPP) get closer to individual user benefits based on demographically explicit travel patterns. An analyst can use the CTPP data to identify the number of commuters by mode between census tracts for the entire country. Trip counts can be combined with travel time information so that trip characteristics can be calculated and summarized for demographic groups.

If a region has an available travel/activity survey or transit rider survey, those data can be similarly used to calculate trip characteristics. The benefit of such surveys is that they encompass travel for all purposes and so provide a more complete picture of travel demand compared to the commute-only trips captured by the CTPP.

User Benefits Based on Logsums

User benefits can be calculated using the denominator of a multinomial logit mode choice model (logsum). User benefits calculated in this way can be interpreted as a measure of accessibility since the logsum represents the overall utility of a given set of choices. Utility is known to depend on characteristics of individuals (e.g., socioeconomic status, gender, household size, automobile ownership) and modes (e.g., time, monetary cost, relative comfort) [134]. Logsums apply different weights to different aspects of each choice (e.g., weighting out-of-vehicle wait times more negatively than in-vehicle travel times) such that real-world decision-making is replicated as closely as possible. By allowing different elements of choices to bear differently on calculated accessibilities, logsums go beyond the trip characteristics measures summarized above. In general, if the number of choices increases or if existing choices are made more attractive, higher accessibilities will result from this measure.

Provided disaggregate data are available, logsums can be calculated for individuals and all trip purposes. Because they can be calculated using regional travel survey data or the underlying choice models embedded in a travel demand model, they are intimately linked to individual travel choices and get as close as possible to true user benefits using currently available approaches.

How to Calculate Featured Accessibility Performance Measures

Case Study: Houston Metro System Reimagining

This next section demonstrates the five measures included in Figure 4-1 using data provided by Houston Metro and the FTA for the Houston metropolitan region. The measures are population counts/shares, access to opportunities, trip characteristics using CTPP data, trip characteristics using rider survey data, and user benefits based on logsums.

Houston presents a fruitful case study location because the agency implemented multiple major service changes beginning in 2014, including two new light rail lines and a major bus system redesign. With a goal of increasing transit ridership by 20% over two years, the Metropolitan Transit Authority of Harris County (METRO) underwent a major service change in August 2015 referred to as System Reimagining (SR). The best and most specific information about the SR effort is on METRO's website (https://www.ridemetro.org/Pages/Reimagining-PlanMaterials.aspx). System Reimagining was the first major redesign of the METRO network in the approximate 30 years of its existence. It also followed the opening of two new light rail lines in May 2015.

The SR improvements focused on the local bus network, specifically increasing the number of bus routes with 15-minute headways or better, shifting from a radial to gridded service pattern, and dramatically increasing weekend service. Figure 4-2 demonstrates the increase in the number of high-frequency routes both before and after SR implementation. Consistent with the raw increase in high-frequency routes, the number of high-frequency route-miles also increased by two-thirds—from 510 to 850 miles. The number of low-frequency route miles shrank from 1,500 to 1,200.

Evaluating SR's performance requires considering both peak and off-peak service. Because the service changes were implemented largely subject to a fixed budget, increasing weekend and off-peak service will require shifting resources from the peak. Examining only peak-period impacts would therefore provide an incomplete picture. While not all measures considered here can be calculated for off-peak periods, the access to opportunities analysis explicitly considers both weekday peak and weekend service to demonstrate how the SR's impacts varied considerably across those two time periods.

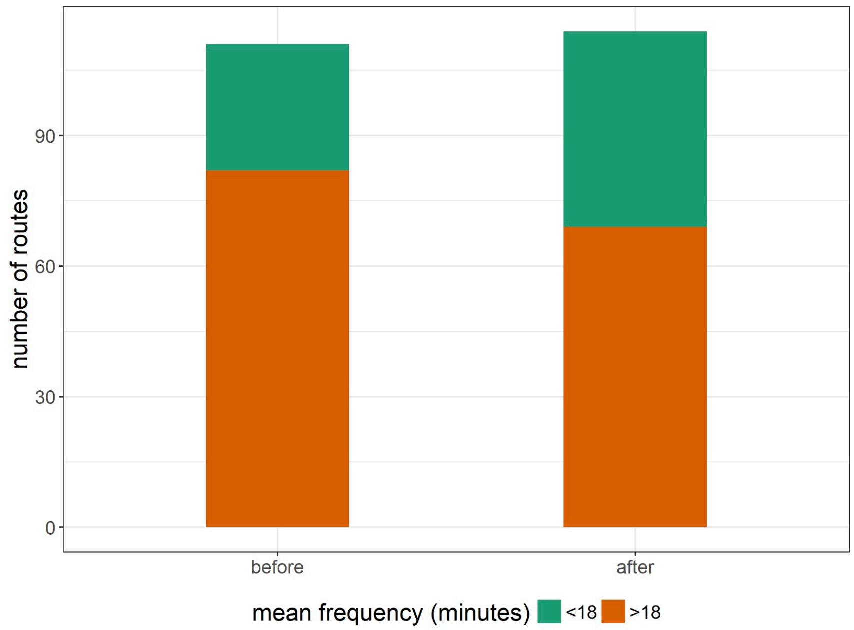


Figure 4-2 *Number of high-frequency (headways < 18 minutes) and low-frequency (headways > 18 minutes) routes before and after SR implementation*

Note: Data gleaned from GTFS feeds created before and after August 15, 2015.

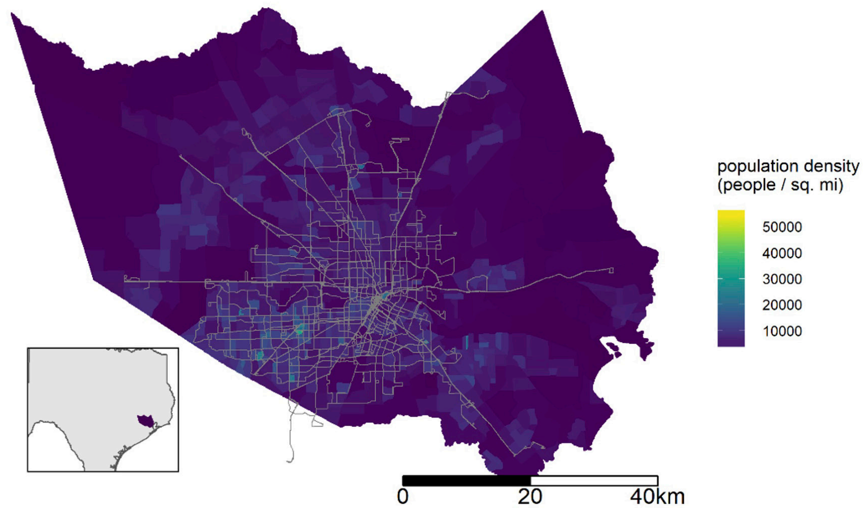


Figure 4-3 *Houston METRO routes (grey lines) as of August 16, 2015, overlaid on population density at the census tract level (people/sq. mi.) in Harris County, TX (location shown in inset)*

Sources: August 16, 2015, Houston METRO GTFS feed and 2011–2015 American Community Survey five-year estimates

Accessibility Analysis Software and Code

All scripts and software necessary to reproduce the spatial analyses presented below are available on GitHub, a social network that facilitates creating, maintaining, and sharing software around the world using principles of software engineering and version control. One key benefit of using GitHub to share software in this way is that it allows many people to view and propose changes, which makes identifying and fixing bugs or errors much easier. The site is organized into "repositories" that store all code related to a specific piece of software or analysis task. The repository related to this report is called "transit-equity-accessibility" and is available at https://github.com/aakarner/transit-equity-accessibility. It will be regularly updated and maintained over time as users experiment with the various approaches, submit bug reports, and propose fixes. Most of the scripts are written in R, but Python is also used for some network analysis tasks. For questions on any of the GitHub content, use its built-in forums and software management tools rather than contacting members of the research team directly.

Each of the five types of measures described below is associated with one or more scripts in the repository and a data folder contains sample data (GTFS feeds, redacted rider survey responses, shapefiles, etc.) necessary to reproduce all the figures and results included here.

How to Calculate Population Counts/Shares

Analyses of demographics and proximity are by far the most common undertaken by public transit agencies because they are described explicitly within FTA guidance documents [4]. Such analyses assume that public transit systems benefit those who live close to stops and stations. This assumption means that any service changes deemed positive will benefit people living close to transit and that negative service changes will burden that population. The method compares the demographics of those who will be affected by a service change to those of the broader service area. Consistent with Title VI and environmental justice guidance, the benefits and burdens faced by people of color and low-income people are generally the focus of any analysis.

Typical service equity analyses based on demographics and proximity use census data to identify the affected population. They proceed as follows:

1) Existing stops, stations, and routes are identified using GTFS data and loaded into a geographic information system (GIS).
2) Euclidian buffers are drawn at 1/4 mile around all bus stops and 1/2 mile around all rail stations in a manner that maintains the link between buffers and route numbers.
3) Buffers are intersected with census units (e.g., block groups or tracts) and joined with appropriate census data sets (e.g., the decennial census or the American Community Survey) to determine counts and shares of population groups living close to each route in a system.
4) A "reference population" is identified using either the demographic characteristics of the city/cities or county/counties in which service is provided or by aggregating over all buffers created in step 3 and creating overall counts and shares within the buffer areas.
5) The next step differs depending on whether service changes affect a single route or multiple routes.
    a) If a single route is affected, its proposed service changes are qualitatively coded as positive (either entirely new service or expansion of existing service) or negative (cuts to existing service). The demographic characteristics of the affected route are calculated. If the change affects an existing route, existing GTFS data can be used. If the change affects a new route or an extension of an existing route, the analyst must represent the new alignment in a GIS.
    b) If multiple routes are affected, each service change is qualitatively coded as positive or negative. An example of this type of analysis is provided by Los Angeles Metro [135].

6) Similar demographic totals are developed for those affected by a service change and the overall service area and the two quantities are compared. The final outcome depends upon whether the share of protected population members exceeds or falls below that in the reference population and whether positive or negative changes are proposed. Four possible outcomes are summarized in Table 4-1.

Table 4-1 *Possible Outcomes from Service Equity Analysis Based on Demographics and Proximity*

Scenario	Outcome	Discriminatory/ Disparate Impact
Service cut (or net negative impacts)	Protected groups overrepresented in affected population	Yes
Service cut (or net negative impacts)	Protected groups underrepresented in affected population	No
Service improvement (or net positive impacts)	Protected groups overrepresented in affected population	No
Service improvement (or net positive impacts)	Protected groups underrepresented in affected population	Yes

It is noteworthy that, according to FTA guidance, either census data or ridership data may be used to evaluate ridership demographics. Ridership data are gleaned from surveys of transit riders conducted on board transit vehicles. These data can also be used to generate route-level and service area demographics. This data source and other potential uses are discussed later in this report.

Example Application

The scripts used to assess population counts and shares rely on two R packages for processing public transit and census data called tidytransit and tidycensus, respectively. These packages (and others) are used to process the before and after GTFS feeds, calculate Euclidean buffers around transit stops and stations, intersect those buffers with census geographies, and calculate the total numbers of people in different racial/ethnic groups represented within them. These calculations can be completed for the entire service area, subsets of the service area (e.g., only for high-frequency routes), and individual routes. Results for two cases are summarized as follows:

- **Any access** – all residents within 1/4 mile of any bus stops and 1/2 mile of any rail stations defined within the GTFS feeds
- **High-frequency access** – all residents within 1/4 mile of bus stops and 1/2 mile of rail stations with 16-minute or better frequency, on an average weekday between 6am and 10pm

Table 4-2 summarizes population counts and shares in the Houston METRO service area. It shows two possible service area definitions, the populations in the entire county (according to the 2011–2015 five-year American Community Survey estimates), and the populations within buffer distances of the transit system both before and after METRO's network redesign, considering service on a typical weekday between 6am and 10pm.

When comparing the two service area definitions, the White population is clearly underrepresented proximate to the public transit system relative to its overall share of the population in Harris and Fort Bend Counties. Asian populations are similarly underrepresented, although the magnitude of the underrepresentation is much smaller. Conversely, Black and Latinx populations are overrepresented proximate to transit relative to their shares in the relevant counties. This means that a higher proportion of Black and Latinx populations live in closer proximity to transit service than their White and Asian neighbors.

Table 4-2 *Houston METRO Service Area Definitions*

		Total	White	Black	Asian	Latinx
County populations		5,014,693	1,611,605	939,276	404,709	1,968,882
			32.1%	18.7%	8.1%	39.3%
Euclidean buffers	Before	1,767,387	434,449	399,801	120,374	785,243
			24.6%	22.6%	6.8%	44.4%
	After	1,772,369	436,325	403,560	120,876	783,579
			24.6%	22.8%	6.8%	44.2%

Figure 4-4 depicts the population totals summarized in Table 4-2. The White and Black populations with any proximate public transit service (including all stops/stations within the relevant GTFS feeds) increase by several thousand after the network redesign, while the Latinx population with access slightly decreases and the Asian population with proximate service remains about the same. Considering these definitions of the service area and service proximity, there appear to be no impacts from the service change in need of attention or mitigation.

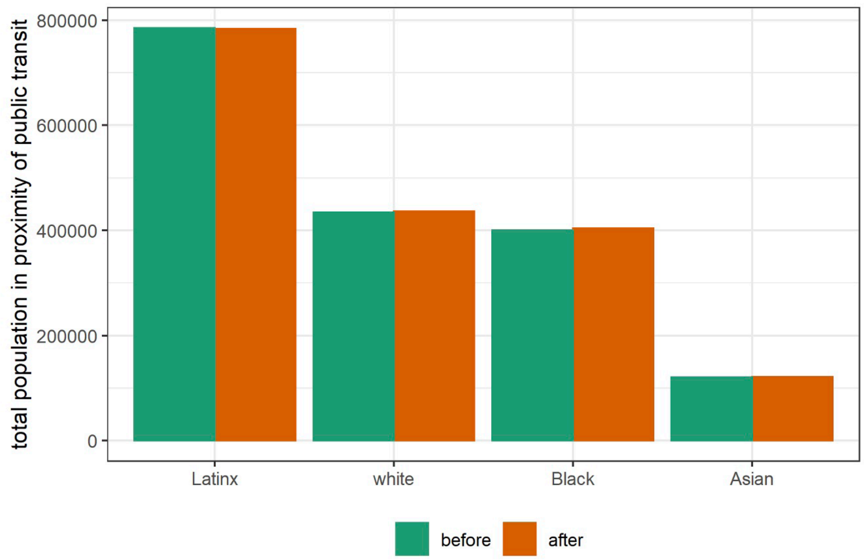


Figure 4-4 *Total population within 1/4 mile of bus stops and 1/2 mile of rail stations by race/ethnicity before and after System Reimagining*

Figure 4-5 shows the population totals for racial/ethnic groups proximate to service with 16-minute headways or better on average between 6am and 10pm. To generate this figure, first tidytransit is used to calculate route-level frequencies, then routes are subsequently categorized into high or low frequency before dissolving the component routes into a single layer. The result is one layer that represents the spatial extent of high-frequency coverage and another that represents the spatial extent of low-frequency coverage. These are intersected with census tracts and population totals are again derived. The figure clearly shows one effect of the System Reimagining—the number of residents with access to high-frequency public transit service increases across all racial/ethnic groups.

The share of the population residing within the buffer-based service area with access to high-frequency service increases from 37% to 51% with the service change. The share of each racial/ethnic group with high-frequency access also increases for all groups.

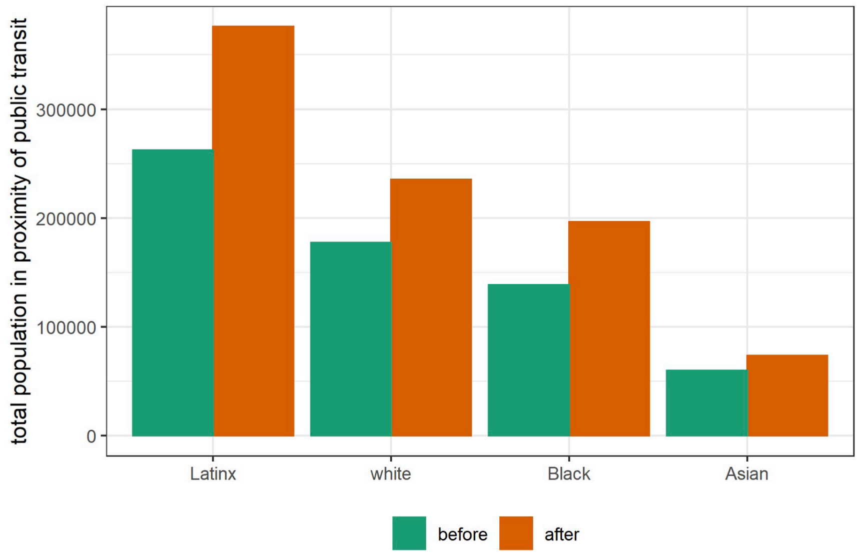


Figure 4-5 *Total population within 1/4 mile of bus stops and 1/2 mile of rail stations with less than 16-minute median headways on weekdays between 10am and 6pm by race/ethnicity before and after System Reimagining*

Grouping all changes together and evaluating impacts at the system-wide level masks the changes that occur on individual routes. Figure 4-6 illustrates another way that the proximity data can be summarized. It shows the routes that appear to be new additions (based on their appearance in the "after" GTFS feed but not the "before" feed) and those that appear to represent cut service (based on their appearance in the "before" feed but not the "after" feed).[7] Cut routes are labeled with red points and new routes are labeled with blue points. The position of each route on the grid represents the share of people of color within Euclidean buffers around that route. The figure's value lies in its highlighting the broad range of demographic characteristics across cut and added service. It can focus attention on those locations with high shares of people of color experiencing service cuts or high shares of White residents experiencing service additions. Of course, other demographics can be analyzed at the same time with small changes to the underlying code.

[7] This method of identifying service cuts and additions is imperfect since some route numbers were likely changed and a nearby route may have had its service improved to compensate for a cut, among a number of other possible compensating actions. Identifying "cuts" and "additions" should be done in consultation with an appropriate local expert.

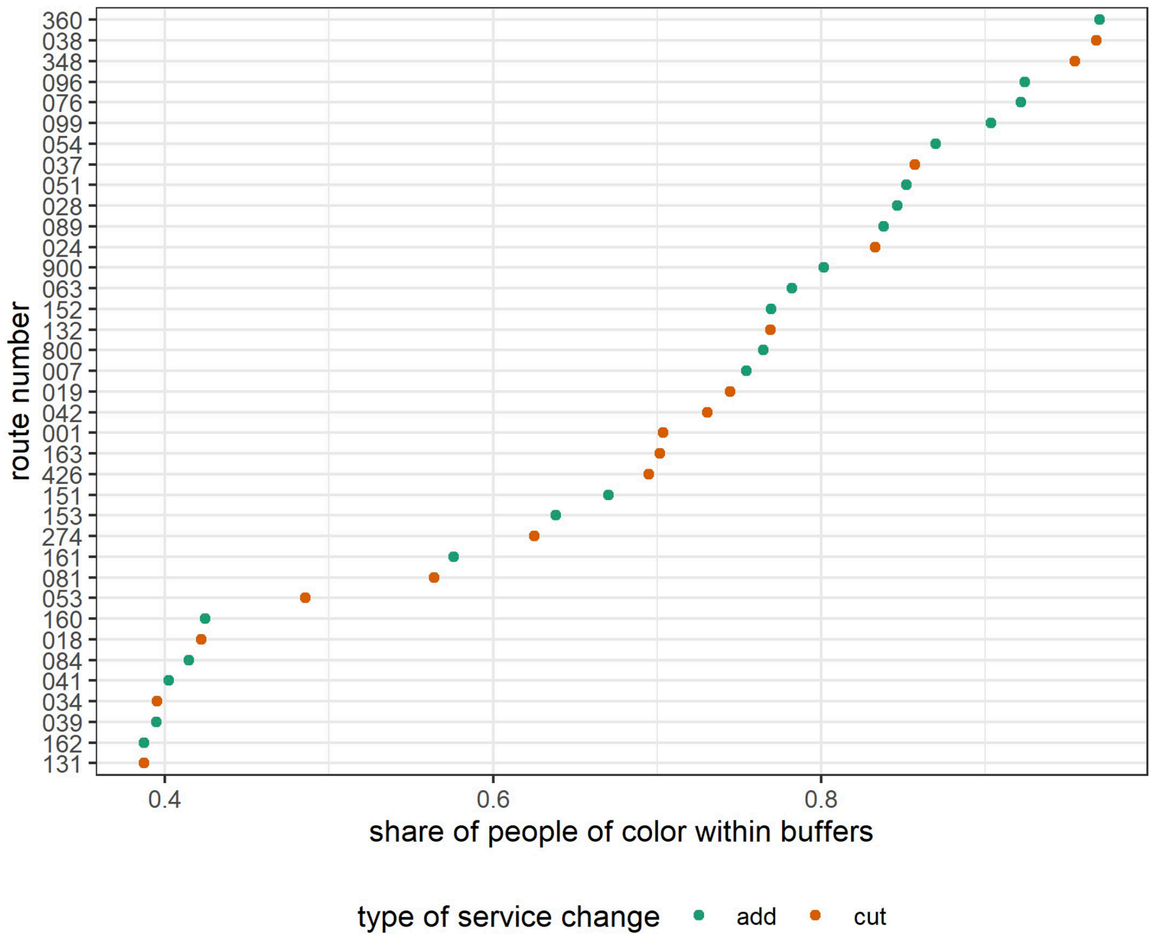


Figure 4-6 *Share of people of color for each route that appears in the "after" GTFS feed but not in the "before" feed (label = add) and each route that does not appear in the "after" feed but does appear in the "before" feed (label = cut)*

Strengths and Limitations

Proximity-based service equity analyses are relatively simple to carry out using publicly available census data and standard GIS functionality. When evaluating a myriad of proposed route changes and options, it is typically not feasible to conduct individual analyses to evaluate each option.

The limitations of this type of approach are numerous. Importantly, census-based analyses do not consider the demand for public transit or the demographics of existing transit users. This means that those actually using public transit are not distinguished in the analysis. This limitation can be mitigated by using ridership data. Furthermore, several assumptions are embedded in this type of analysis due to practical data constraints. First, the calculation of a Euclidian distance buffer aggregates data within a distance as the crow flies, but does not take in to account geographic barriers, street connectivity, existing sidewalk network, or other factors that would result in smaller areas with access to the transit system. Second, these analyses must develop some method to quantify the distribution of population across census block groups intersected by the buffers. While it is possible to generate a representative model of development intensity based on remote sensing of aerial imagery, most agencies instead simply assume an equal distribution of all population indicators across each census block group intersected in the analysis.

How to Calculate Access to Opportunities

Access to opportunities approaches are common in the literature and in practice. Typically, the measures quantify the number of opportunities that can be reached from origin locations (e.g., census tracts or block groups) in a region within a time threshold. A typical measure would assess the average number of jobs reachable from all origin locations in a region within a 45-minute public transit trip weighted by the population at the origin.

In a service equity analysis context, such measures assess how the ability to reach opportunities will be affected by a proposed service change. Changes in access to opportunities can be assessed for different demographic groups using different approaches to community identification [e.g., 136]. In this sense, access to opportunities approaches are more sophisticated than demographic counts and shares in terms of their representation of benefits; they account for differences across system improvements as opposed to treating them all equally. These approaches still do not consider the actual demand for travel or incorporate data about people currently using transit.

Typical service equity analyses based on access to opportunities would proceed as follows:

1) Information on public transit stops, stations, routes, and schedules are identified for the no-build (current) and build (project) scenarios using GTFS data and loaded into a GIS capable of assessing network travel times and/or costs. Analysts commonly use ArcMap's network analyst extension for this purpose, but OpenTripPlanner and r5r [137] are other convenient, free, and open-source options.

2) Travel times between relevant origins and destinations are calculated under the no-build and build scenarios. Origins and destinations can be all public transit stops and stations, or centroids associated with convenient geographic units (e.g., census tracts, block groups, or blocks). Smaller spatial units are usually preferred since as they become larger, calculated walk times will be less representative of actual conditions.

3) Opportunities are quantified for each spatial unit (e.g., walksheds around transit stops, or entire census tracts or block groups) using information about total jobs (potentially disaggregated by industry classification, wage level, or other characteristics of interest), facility locations, or facility characteristics (e.g., square feet of retail space).

4) For each origin location, the number of opportunities accessible is quantified under the build and no-build scenarios using one of two approaches:

    a) *Travel time threshold.* Under this approach, a travel time threshold is selected (e.g., 30, 45, or 60 minutes) and all opportunities reachable from an origin within that amount of time are summed.

    b) *Gravity measure*. With a gravity measure, all opportunities are considered accessible from each origin, but nearer opportunities are more accessible than those farther away. All opportunities are discounted using a factor that can be calibrated using local data on observed trip patterns.

5) Once access to opportunities measures are calculated, they must be summarized for the protected populations and reference populations. There are three options for such summaries [136]:

    a) *Demographic thresholds*. In this approach to summarizing access to opportunities, groups of spatial units (e.g., tracts, block groups, or transportation analysis zones) are identified using their share of protected populations. For example, an analysis might group all tracts together that contain more than 40% low-income people and identify them as "disadvantaged." Conversely, all tracts that contain fewer than 40% of the relevant population become the "reference" tracts.

    b) *Population-weighting*. With population weighting, outcomes for every member of the protected population are included in the final summaries by default. Average measures are constructed by using the population numbers in each spatial unit combined with the accessibility measures calculated for that same unit. Population-weighted averages are then calculated using the accessibility as the measure and the populations as the weights.

    c) *Community identification*. In this third approach for summarizing access to opportunities measures, relevant communities are identified at the beginning of the analysis [138]. Communities could be represented by census places, groups of tracts or transportation analysis zones (TAZs), or any other convenient grouping.

Each of these approaches to summarizing results has strengths and limitations. For example, community identification can be a powerful way to incorporate local knowledge into service change equity analyses, but available geographic units might not comport well with local understandings of community boundaries. Demographic thresholds are easy for the public to understand but mix population members from both protected and non-protected groups. Calculating weighted averages over the entire region can also miss important local conditions.

6) Finally, outcomes are compared between the protected groups (however defined) and the reference population. Analysts can examine differences between the population groups at no-build and build, as well as the change between the build and no-build conditions. Both percentage changes and absolute totals for the metrics should be assessed.

Example Application

The research team calculated public transit travel times using OpenTripPlanner (OTP), open-source software that can be used for various purposes including multimodal trip planning, skimming information about shortest-path trips from public transit networks, and generating other measures of public transit performance. Travel times were later reproduced using a newer open-source option called r5r [137]. Results were similar in both cases.

The travel times calculated here included walk access time (assuming a 3-mph walk speed), initial wait, in-vehicle time, and walk egress time. Any transfer walk/wait times were also captured. OTP and r5r are commonly used to generate travel times and other public transit trip characteristics (e.g., number of boardings, walking time, and waiting time). There are multiple OTP entry points, including an application programming interface (API) and Python scripting. r5r is implemented entirely in R. Here, r5r was used, which had the advantage of ensuring a reproducible workflow, easy parallelization, and rapid execution. R was used to generate the travel times that were subsequently analyzed in combination with demographic information.

For the purposes of illustration, travel times were calculated between all hexagonal cells reachable within 60 minutes of total travel time during the morning peak period (departures between 6am and 8am) on a typical weekday and the same measure for Sunday afternoon (departures between 12pm and 2pm). Tuesday May 12/Sunday May 17, 2015 were the representative “before” days and Tuesday August 25/Sunday August 30, 2015 were the representative "after" days. For each, departure times were randomly sampled within 15-minute slices of each two-hour period, resulting in eight independent estimates of travel time. Accessibility measures for each departure were subsequently calculated using information on total jobs taken from the 2015 Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES) dataset maintained by the US Census Bureau. These were aggregated using measures of central tendency and summarized for different demographic groups using the 2011–2015 American Community survey five-year estimates.

To ensure that infrequent but rapid service was not erroneously assigned a high accessibility value, final accessibility indicators were manually calculated for each origin by summing all jobs accessible over all departure times and dividing by eight (i.e., the number of estimated travel times). This step ensured that an origin-destination pair with one quick trip (e.g., commuter service) available during the morning peak did not appear as having high-quality service. Computationally, setting a low travel time threshold and calculating accessibility in this manner is attractive because it reduces execution time substantially when using OTP. Solving the entire Houston METRO network for eight departure times and all destinations reachable within 60 minutes using OTP took approximately 20 minutes on a desktop computer with 32 GB of RAM and 10 Intel Xeon 2.20 GHz processors running in parallel. On the same hardware, r5r solved the network in approximately five minutes even with the threshold increased to 180 minutes.

Another clarification is in order relevant to others who wish to use OTP to calculate travel time estimates. By default, OTP "clamps" or eliminates a user's initial wait time to zero, a necessary step for route planning but one with a baleful impact on accessibility analysis. Eliminating initial wait times will unfortunately enhance the attractiveness of infrequent service. Part of the benefit of frequent service is that the likelihood of a long initial wait is reduced. It is possible to disable initial wait clamping so that trips depart precisely at the requested departure time and incur any initial wait required. Taking this approach also ensures variation in the estimated travel times, since many time estimates generated with a clamped initial wait will be identical. No action is necessary to disable initial wait clamping in r5r.

The extent to which the combined capital and service changes undertaken by Houston METRO in 2015 affected the overall level of accessibility across the region can be identified through visual inspection of maps and comparing summary statistics across the region. Such analyses serve an important quality assurance/quality control purpose, ensuring that the results "make sense" given the goals of the service change.

When evaluating SR's impact, considering both peak and off-peak service is necessary to produce a complete picture of the change. Accordingly, Figures 4-7 and 4-8 show overall accessibility changes after the combined service and capital changes for the Tuesday peak period (6–8am) and Sunday service (12–2pm), respectively. For each hexagonal grid cell, the figures show the difference in 60-minute cumulative opportunities accessibility such that positive values plotted on the map indicate that cumulative opportunities increased after SR implementation. The legend for both figures represents the same range of values, which facilitates comparison. The map comports with expectations; in general, weekday peak peripheral accessibility decreases (shades of red) while accessibility in the core increases or stays the same (shades of green). On the other hand, Sunday service increases dramatically, with concomitant increases in accessibility in most areas.

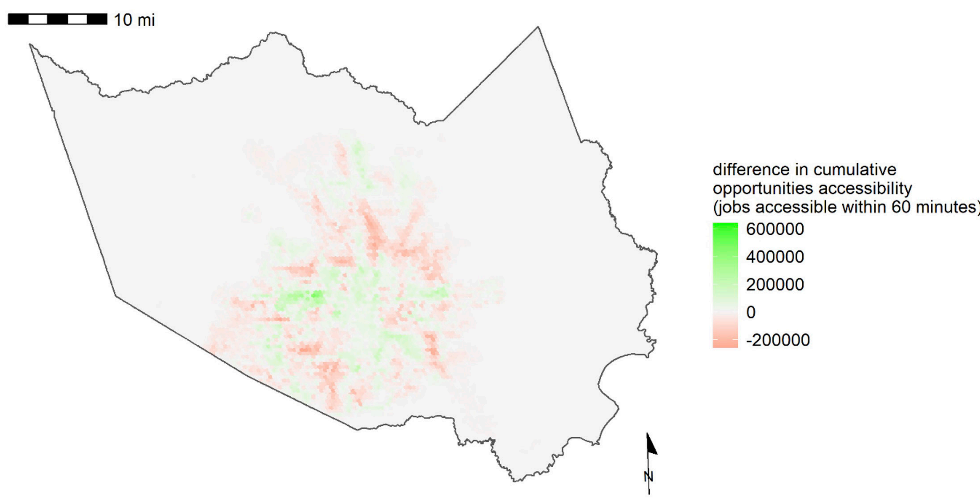


Figure 4-7 *Change in cumulative opportunities accessibility (number of jobs accessible in less than 60 minutes) with SR implementation on a Tuesday during the morning peak period (6–8am)*

Note: Positive values indicate greater accessibility after the combined capital and service changes.

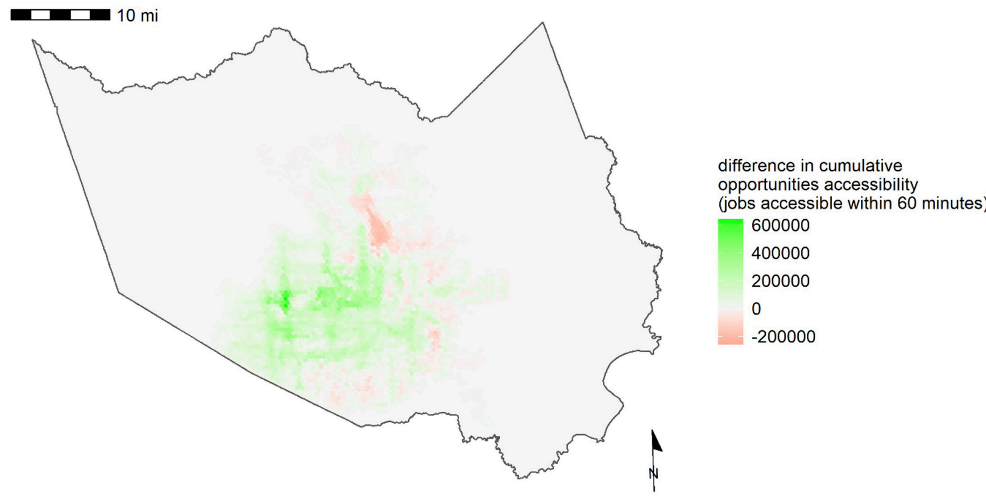


Figure 4-8 *Change in cumulative opportunities accessibility (number of jobs accessible in less than 60 minutes) with SR implementation on a Sunday afternoon (12–2pm)*

Note: Positive values indicate greater accessibility after the combined capital and service changes.

These changes will affect different demographic groups differently depending on where they reside within the service area. One way to examine the effects of such changes is to calculate population-weighted means for each group before and after the changes. These means are summarized in Tables 4-3 and 4-4 and are presented separately for all locations in the county as well as those within viable walk-to-transit markets (i.e., within one mile of a transit stop). Table 4-3 demonstrates that overall during the peak period, cumulative opportunities accessibility to all jobs decreases modestly due to SR and related capital investments for all demographic groups. This result is not entirely unexpected; in order to increase frequency on a small number of routes, service must be cut on a relatively larger number of less frequent routes. The results in Table 4-3 demonstrate that on net during the peak period, more people experience reduced, rather than increased, accessibility. In contrast, Table 4-4 demonstrates across-the-board and substantial increases in accessibility for all groups on Sunday afternoons.

Both tables also show that prior to SR implementation there are vast differences in the accessibility experienced by different demographic groups in Harris County. When considering the entire service area, differences between groups are relatively muted. On average, Harris County residents have access to between approximately 180,000 and 210,000 jobs within 60-minutes of door-to-door public transit travel time during the peak period. But when looking at only those areas within walking distance of transit (i.e., with zone centroids within one mile of a transit stop), the differences are much starker, with Black and Latinx residents having access to only between 250,000 and 280,000 jobs, while Asian and White residents have access to between 330,000 and 400,000 jobs.

This bifurcation indicates that when living close to public transit, White and Asian residents enjoy comparatively higher levels of service than the Black and Latinx populations. The propensity for selecting residences near public transit differs across groups. The share of White residents in Harris County living within one mile of a public transit stop or station is 45%, while the shares for Black, Latinx, and Asian residents are much higher at 72%, 65%, and 62%, respectively. In general, these disparities are reproduced for Sunday service and are not mitigated by SR-related changes.

Table 4-3 *Population-Weighted Average Jobs Accessible within 60 Minutes Before and After SR during Tuesday Peak Period (6–8am)*

	Harris County		Transit Accessible Zones (within 1 mile of a transit stop/station)		Pct. Change
Race/Ethnicity	Before	After	Before	After	
White	176,144	177,122	403,918	406,161	+0.6%
Black	179,473	173,446	252,948	244,453	-3.4%
Asian	207,174	207,908	335,242	336,430	+0.4%
Latinx	179,226	170,773	277,831	264,728	-4.7%
All four groups combined	180,136	175,790	306,344	298,953	-2.4%

Note: The percentage changes are the same regardless of the geographic definition used because those outside of transit accessible zones have zero accessibility both before and after SR. Demographic counts are taken from the 2011–2015 American Community Survey five-year estimates. Access to opportunities figures were calculated following the methods described in this section.

Table 4-4 *Population-Weighted Average Jobs Accessible within 60 Minutes Before and After SR during Sunday Afternoon (12–2pm)*

	Harris County		Transit Accessible Zones (within 1-mile of a transit stop/station)		Pct. Change
Race/Ethnicity	Before	After	Before	After	
White	115,503	161,683	264,860	370,758	+40%
Black	111,014	146,376	156,461	206,301	+32%
Asian	126,122	185,382	204,086	299,980	+47%
Latinx	111,333	145,290	172,586	225,225	+31%
All four groups combined	113,600	153,444	193,191	260,950	+35%

Note: The percentage changes are the same regardless of the geographic definition used because those outside of transit accessible zones have zero accessibility both before and after SR. Demographic counts are taken from the 2011–2015 American Community Survey five-year estimates. Access to opportunities figures were calculated following the methods described in this section.

SR clearly results in an altered accessibility landscape across Harris County. But the population-weighted analysis is inherently limited because it does not include any information about public transit markets or ridership potential. Later measures presented in this report will consider such information.

Strengths and Limitations

Access to opportunities indicators are extremely common in both the academic literature and transportation planning practice. Their strengths and weaknesses vary depending on the manner in which accessibility is operationalized. Travel-time threshold approaches are interpretable because the calculated measures represent the total number of opportunities (e.g., jobs, square feet of retail space, number of facilities) accessible within a travel time threshold. A weakness of the threshold approach is that the threshold represents a hard boundary—those immediately before the threshold are considered accessible while those immediately after the facility are considered inaccessible. Gravity-based measures circumvent this limitation by considering all opportunities, but the final measure calculated is not interpretable as the number of opportunities since they will have been multiplied by a decay factor. In this sense, only general comparisons of accessibility results are possible.

The major weakness that underlies every access to opportunities measure of this type is that travel demand is generally not considered when calculating the metrics. This means that there is not necessarily a relationship between actual travel demand—through the collection or projection of existing/future rider origins and destinations—and calculated metrics. In locations where access to opportunities is high, demand for the types of opportunities measured may be low. It is possible to adjust access to opportunities measures to account for certain aspects of demand. For example, travel time thresholds can be adjusted based on observed trip distances for locations or demographic groups [e.g., 139, 140]. Under this approach, multiple values of accessibility would be calculated for a single geographic unit but would apply to different populations residing within that unit.

How to Calculate Trip Characteristics Using CTPP Data

The Census Transportation Planning Package is a special tabulation of the American Community Survey's transportation- and commute-related questions. ACS contains questions regarding home and work location, regular commute mode, and departure time. These questions are combined with the demographic information inherent in ACS to generate cross-tabulations and commute flows at the census tract level. In an analysis of service changes based on CTPP data, changes in travel times, waiting times, and number of transfers by demographic group can be examined. These data are a type of accessibility measure because they assess the ease with which individuals can reach specific destinations they value. Additionally, less time spent traveling to observed destinations opens up some share of an individual's overall travel time budget.

CTPP data are reported in three "parts" at different levels of geography. Part 1 includes information summarized for commuters at their place of residence. Part 2 includes information summarized for commuters at their place of work. Part 3 includes information about the flows of commuters between their residences and workplaces. Different cross-tabulations are available in each part. For example, using Part 1 data allows retrieval of the number of public transit users who reside in each tract who are also people of color. Part 3's flow data contains trip counts disaggregated by mode, but cross-tabulations are only available for some combinations of demographics (e.g., age, household income, vehicles available). No cross-tabulation is available between mode and minority status, but such a table is required to conduct an equity analysis of potential service changes that considers outcomes for different racial and ethnic groups.

It is possible to create a synthetic minority status/mode flow table using an iterative proportional fitting (IPF) approach that integrates information from all three parts of the CTPP. Part 1 contains a cross-tabulation of mode by race/ethnicity for origin locations. Part 2 contains the same cross-tabulation but for destination locations. Part 3 contains total trips between all origin-destination (OD) pairs. In effect, the IPF procedure splits the Part 3 table into two—one for the White population and one for people of color, the two racial groups identified in CTPP. To create initial seed tables, the overall share of public transit users across the combined statistical area can be used and the rows and columns balanced so that their sums equal the Part 3 totals. Figure 4-9 illustrates the general IPF procedure.

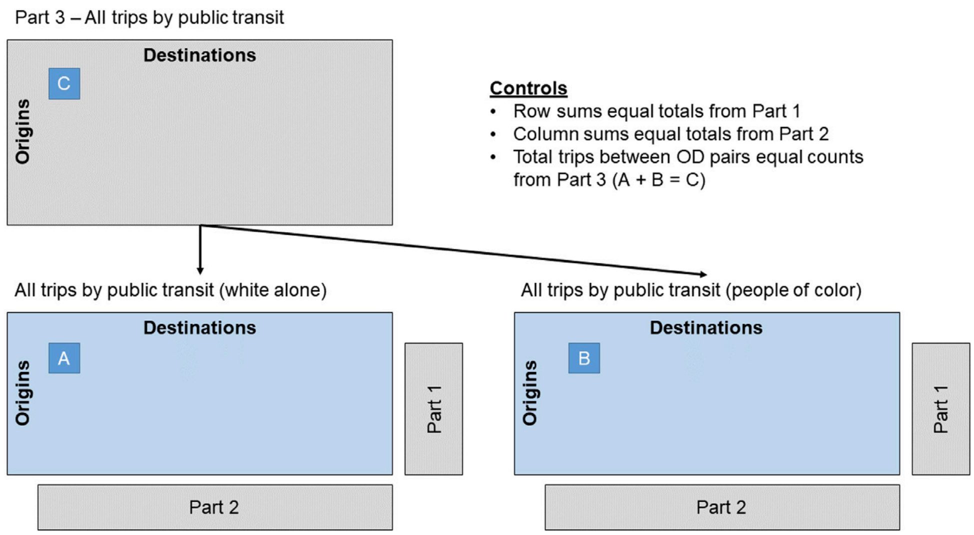


Figure 4-9 *Approach to defining constraints using CTPP data (grey boxes = available input data and relevant CTPP "part"; blue boxes = synthetic data to be created)*

Once the required tract-level origin-destination flow data are assembled, an analysis of service change equity can be conducted. Steps 1–3 are identical to those required for the access to opportunities approach. These involve assembling relevant GTFS feeds and calculating travel times and other trip characteristics (e.g., number of transfers, wait time, walk time, in-vehicle time, out-of-pocket cost) before and after the proposed service change using OpenTripPlanner or another suitable path-building algorithm.

Special care should be taken to separately estimate travel times for walk-to-transit and drive-to-transit paths, especially if drive-to-transit comprises a substantial share of a given agency's ridership. CTPP does not separately enumerate drive-to-transit trips, so the analyst must devise a method for identifying them. One possibility is to assume that if the first-mile portion of a trip exceeds some distance threshold (e.g., one mile) and is located near a park-and-ride station, the trip will be assumed to use that mode. Modeling kiss-and-ride trips using CTPP data would be somewhat more challenging and requires input from knowledgeable local partners.

Once appropriate travel times are calculated, the analysis proceeds as follows:

1) Identify travel characteristics for each trip. This step involves associating every origin-destination pair with all desired trip characteristics both before and after a service change. More specifically, if each row in a dataset represents an OD pair, each column should represent a different type of characteristic.

2) Summarize trip characteristics for demographic groups or places. Once trip characteristics are associated with all CTPP trips, appropriate summary statistics can be calculated. These could include means, medians, and standard deviations for all trips undertaken by a particular demographic group or that originate/are destined for specific locations.

3) Compare results across groups before and after the service change. Examine the pre- and post-service change trip characteristics both in absolute terms and for percentage changes.

Example Application

An example application to service change equity analysis is presented here using 2006–2010 CTPP data and appropriate GTFS feeds gleaned from Houston METRO, again considering their SR. Basic information extracted from CTPP demonstrates substantial differences in travel behavior between people of color and White travelers. Figure 4-10 shows commute destinations (i.e., places of work) for people of color and White residents separately. The difference is stark. The Downtown and Medical Center neighborhoods are clearly major trip attractions for both groups, but commute destinations for people of color are much more widely dispersed than those for White residents. These differences will affect calculated levels of service for both groups.

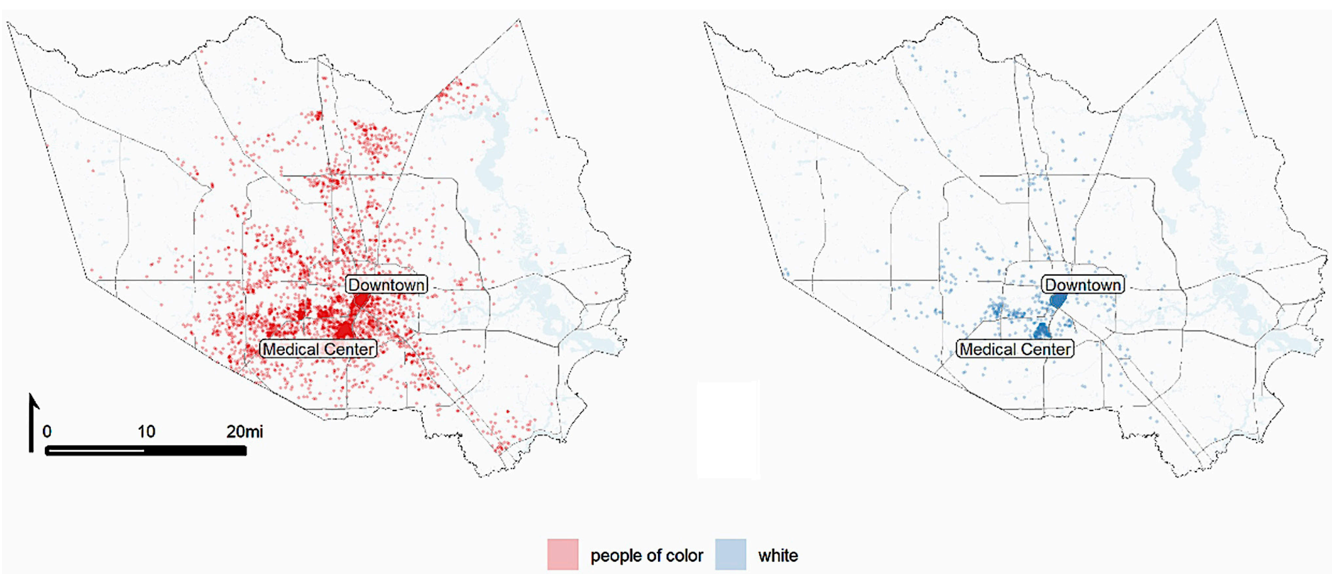


Figure 4-10 *Location of public transit commuters with destinations in Harris County, TX, at their place of work, shown separately for White residents and people of color (one dot = 10 commuters)*

Source: 2006–2010 CTPP Part 1

There are also notable differences in the propensity to use public transit for both groups. Using data from CTPP Part 1 extracted for the 14-county combined statistical area (CBSA) encompassing Houston-Baytown-Huntsville, TX, there are 17,262 linked commute trips made by public transit for the White population and 50,282 for the people of color population. This 26/74 split is quite different from the population shares of each group in the CBSA, which are 41/59 according to the 2006–2010 ACS five-year estimates.

Table 4-5 summarizes trip characteristics for the overall public transit commuting population and two demographic groups (White and people of color). Each cell in the table is a trip-weighted estimate that uses the number of trips gleaned from the synthetic CTPP tables as weights combined with the particular performance measures generated for each origin-destination pair. In general, the measures tell a story that points in a similar direction to the access to opportunities measures. According to the measures included in Table 4-5, only in-vehicle time is reduced after SR, and it declines only marginally. The number of transfers and wait times at those transfers generally increases after SR implementation. Total travel times and walk times also increase. These changes are all consistent with the SR vision—route consolidation, longer walks to more frequent service, and one-transfer trips between almost all destinations. As mentioned above, SR also sought to increase transit mode share on weekends, something that will not be captured by an analysis focusing on peak-period trips.

Table 4-5 *Trip-Weighted Mean Public Transit Performance Combining CTPP Synthetic Trip Data with Performance Measures Calculated Using Before and After SR GTFS Feeds*

	Overall			People of Color			White		
	Before	*After*	*Pct.*	*Before*	*After*	*Pct.*	*Before*	*After*	*Pct.*
Travel time (min.)	67.7	69.2	2%	68.9	70.4	2%	59.6	61.1	3%
Walk time (min.)	19.5	20.5	5%	19.6	20.7	6%	18.4	19.2	4%
In-vehicle time (min.)	39.4	38.7	-2%	40.2	39.4	-2%	34.5	34.4	0%
Wait time (min.)	8.8	9.9	13%	9.08	10.3	13%	6.75	7.45	10%
Number of transfers	0.55	0.66	20%	0.57	0.69	21%	0.42	0.49	16%

Differences are also evident between the two racial groups that are consistent with the access to opportunities measures. Each of the performance indicators is worse overall both before and after SR. In some cases, the percentage change in performance for commuters of color indicates a greater proportional benefit (in-vehicle time) or smaller disbenefit (travel time) than for White travelers. Importantly, these user benefit-type measures reflect actual impacts on people using public transit prior to SR implementation. They therefore differ conceptually from those measures that examine pure changes in access to opportunities.

Strengths and Limitations

In contrast to proximity and accessibility metrics, CTPP embeds information about how people travel, which allows assessing the effects of service changes on people traveling throughout a public transit network.

There are three important limitations associated with CTPP data: (1) demand for travel is assumed to be static (no changes occur in OD trip patterns as a result of proposed service changes); (2) the data only concern commute trips; and (3) no information is available about non-walk-transit-walk paths. No drive-transit-walk paths were generated in summarizing these results, even though Houston METRO has a substantial park-and-ride ridership base (approximately 10% of average weekday riders).[8]

How to Calculate Trip Characteristics Using Transit Rider Surveys

Public transit rider surveys can provide a detailed view of user options, attitudes, and travel behavior. Two different types of surveys are typically conducted. The first is a customer service–oriented survey that asks riders about their level of satisfaction. Customer service surveys might also collect demographic information about riders, and they may or may not be statistically controlled. On the other hand, origin-destination surveys collect detailed information from a random sample of transit riders such that, once properly weighted and expanded, they represent all OD travel in a system. These surveys involve users reporting on their boarding and alighting locations, trip purpose, fare media, and detailed demographics.

Importantly, transit rider survey data can be used to improve reliability and accuracy within transit agency analyses by reflecting actual choices riders are making. Importantly, revealed travel behavior data can be used to ground truth and better understand other sources of data that transit agencies routinely collect, including those generated by automated passenger counters and smart fare cards. Transit riders' revealed preferences, including boarding, departing, and ride frequency, as well as their experiences, challenges, and needs, can be obtained through transit rider surveys [79].

Larger public transit agencies regularly conduct representative surveys of their riders. Contemporary best practices for such surveys involve deploying teams of data collectors into the field to interview transit users and following a robust sampling strategy related to randomness and representativeness at the route, route-direction, and/or route-segment levels. Heavily traveled or otherwise important routes are generally oversampled to generate rider demographics with greater spatial resolution (e.g., stop-level boardings for a light rail line), while routes with lower ridership are sampled less heavily (e.g., lightly used local bus routes).

Transit rider surveys facilitate collection of information about transit user demographics and travel behavior. These surveys offer substantial improvements over CTPP data in terms of both their representation of user

[8] https://www.ridemetro.org/Pages/RidershipReport.aspx

benefits and travel demand. In terms of benefits, they represent much more spatially and temporally resolved information about trip origins and destinations. And in terms of demand, they include a statistically significant sample depicting information about all public transit travel in a system, as opposed to the commute trips available within CTPP. This trip and demographic information can be combined with travel times throughout a transit network before and after a service change to examine impacts on specific groups of transit users, at specific times of day, and for particular trip types.

The research team found multiple examples of agencies using survey data to better align service with customer needs.

- Rabbittransit completes customer satisfaction surveys on its fixed route and demand responsive services in alternating years. The questions are largely on an agree/disagree scale, but the surveys also include open-ended questions asking riders about how the service could be improved. Rabbittransit's executive director Richard Farr states that the survey data produces a comprehensive understanding of the transit system, allowing the agency to better match rider needs [79].
- The Champaign-Urbana Mass Transit District uses anonymous location and movement information gleaned from StreetLight data in combination with a new origin-destination rider survey to determine how well its existing service meets customer needs [113].
- The Washington Metropolitan Area Transit Authority (WMATA) uses transit rider survey data within its Title VI equity impact evaluation process. For bus, rail, and paratransit services, the agency collects demographic and income data from onboard passenger surveys. The data from the surveys is subsequently spatially joined with census data on minority status at the TAZ level. This allows staff to analyze how service changes will impact trip-making patterns for minority and low-income transit riders [141].
- MBTA collects data from both customer satisfaction and OD surveys and these are sometimes combined to evaluate questions of interest. For example, origin-destination survey data were used to calculate various performance measures in the MassDOT bicycle plan created in May 2019 [78]. Survey data were used to calculate the share of public transit trips six miles or shorter whose access and/or egress mode was bicycle [78]. Understanding travel behavior to and from transit stops is another key use of transit rider survey data by transit agencies. The agency also uses the results from their OD surveys, which are fully statistically controlled and representative, to weight the results of its customer satisfaction surveys.

Finally, other types of surveys can be conducted.

- MBTA used a non-rider survey to better understand why residents of the region choose not to travel by rail for its Rail Vision project [142]. The survey allowed participants to specify service preferences, including convenience, express versus local, time of day, and geographic region (142). Gathering feedback about rail service from non-riders can offer insights regarding how service can be improved to serve new customers.

Developing locally specific transit rider survey data is one of the most important tools for conducting accurate equity analyses. Using transit rider survey data to improve and understand transportation equity allows for large-scale insights into the experiences and behaviors of riders. The subsequent section on travel demand modeling illustrates the full potential to which rider survey data can be put.

Example Application

The Houston-Galveston Area Council (H-GAC), the metropolitan planning organization in the 13-county Texas gulf coast, and Houston METRO regularly collaborate to conduct transit rider surveys to generate reliable information about transit ridership at the route and route-segment level across its network of fixed-route bus and light rail. This information helps METRO (and seven other smaller transit providers in the region[9]) better understand the travel patterns of transit users for service planning purposes. This rich dataset can also be used to examine equity outcomes before and after these changes if surveys are timed appropriately. As shown in Table 4-6, four surveys were completed between 2007 and 2017, encompassing major periods of system and capital changes at METRO, including the System Reimagining as well as multiple major light-rail improvements.

Table 4-6 *Houston METRO Transit Rider Surveys Undertaken Since 2007*

Time Period	Survey Type	Sponsoring Agency
2007	Paper	Houston METRO and H-GAC
2011	Paper	Houston METRO
09/2014 – Park-and-ride 02/2015 – 04/2015 – All other routes	Paper	Houston METRO
2017	Tablet	Houston METRO and H-GAC

To examine the impacts of proposed service changes on existing riders, methods similar to those used for CTPP data can be employed. Onboard surveys are expanded to generate representative information regarding the ridership of an entire system. The resultant trip tables can be combined with appropriate travel time information to generate measures of trip characteristics for all trip times at all times of day, with appropriate demographic summaries.

[9] In addition to Houston METRO, seven other transit providers serve the H-GAC region providing a mixture of local bus and park & ride express services: The Woodlands, Fort Bend Public Transportation, Galveston Island Transit, Connect Transit, Harris County Transit, Conroe Connection, and Brazos Transit District.

Figure 4-11 demonstrates how transit rider survey data can be used to assess service change impacts using the 2014–2015 Houston METRO survey data, since those data were collected close to System Reimagining's implementation. Here again, OpenTripPlanner was used to generate travel time estimates. But rather than estimating a travel time during the peak period for every possible origin-destination pair using zonal centroids, actual departure times and latitude/longitude coordinates can be used to provide precise travel time estimates for actual trips. Combined with appropriate expansion factors, trip characteristics such as those summarized in Figure 4-11 can be generated. In this case, the trip characteristics show only modest differences before and after the network redesign.

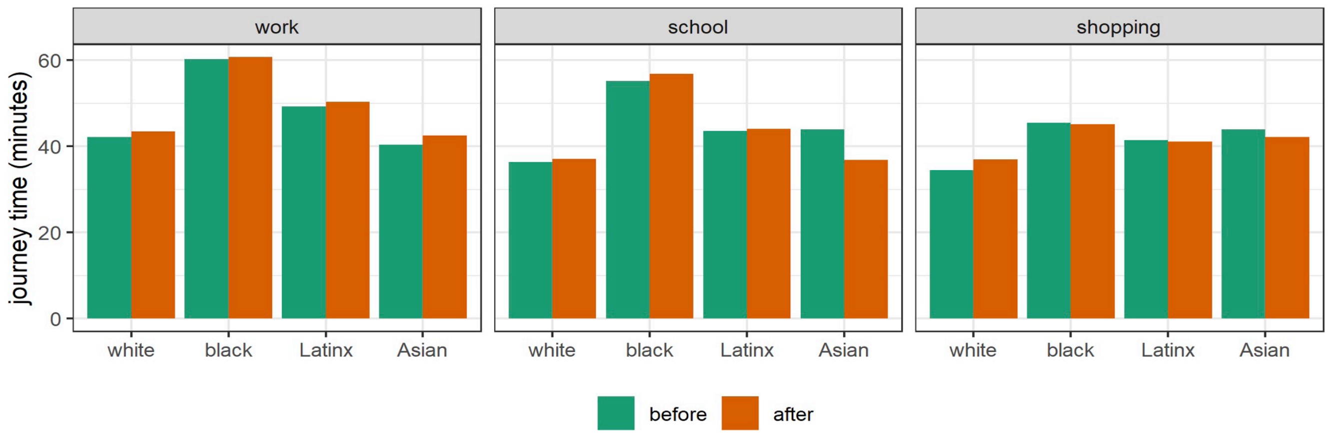


Figure 4-11 *Changes in total journey time across trip purpose and racial/ethnic group using Houston METRO's 2014–2015 transit rider survey data*

Strengths and Limitations

Transit rider survey datasets can be rich with detailed information on actual travel patterns. If collected before and after a potential service change, they offer the potential to glean insights into the impacts of the service change itself on existing passengers. If two waves of survey data are available, it becomes possible to examine how travel patterns changed in response to changing public transit service. If only one wave of a survey is undertaken prior to changing service, those data can be used to estimate the effects of a service change on existing riders. Examining the impacts of a service change on existing customers can provide an important benchmark for equity assessment.

Survey design is also flexible and can measure impacts before and after a project's implementation (with caveats). They can incorporate stated preference elements that identify the potential future travel impacts of a project that does not yet exist. They can also use revealed preference elements to examine the effects of a project after it has been completed. Generally, revealed preference surveys are more telling because people simply report how they responded to a change, but an obvious limitation is that they cannot feasibly be administered before the changes occurs. Stated preference surveys allow respondents to identify choices they would make in some future scenario. It is important to keep in mind that respondents are frequently overly optimistic when imagining future choices.

One drawback of consistently using onboard survey data to assess service change impacts is the process of generating and acquiring the data itself. Survey design and administration to generate statistically significant and representative results is no small task and many transit agencies employ consulting firms to conduct origin-destination surveys on their behalf. Smaller agencies may not have the resources or funds to conduct them at all, much less as a regular fixture of capital or service changes. As such, this type of analysis is likely only feasible for major system changes affecting multiple routes (e.g., before/after major bus network redesigns). The resources required to conduct this analysis would likely not be available or justified for smaller route changes or system adjustments. Transit agencies can partner with other transportation providers and planning organizations to develop and analyze data, leverage existing partnerships, engage stakeholders, and reduce costs.

How to Calculate User Benefits Based on Logsums: Travel Demand Models Using FTA's Simplified Trips-on-Project Software (STOPS)

Travel demand models are used around the world to simulate travel behavior across entire jurisdictions ranging in scale from a city to a region to a megaregion or state(s). In practice, such models embed different statistical models that are run in series, with the outputs from one becoming the input to another. Key input data sources include regional travel/activity surveys, publicly available census data, land use information, and demographic projections. Outputs include summaries of travel behavior (e.g., trip rates, mode shares, automobile ownership) and performance on specific facilities and modes (e.g., automobile levels of service and transit ridership and crowding).

Travel demand models vary widely in sophistication and data requirements. The simplest models have only three steps, the most common models have four steps, and the most advanced models are activity-based and involve incorporating many more statistical models. Three-step models combine trip generation, trip distribution, and traffic assignment, while four-step models add a mode choice step prior to assignment. Activity-based models often include models that predict residential and workplace locations, automobile ownership, tour frequency, tour mode choice, trip mode choice, and assignment. Other sub-models might be included to represent joint travel as well.

Importantly, and differently from all other candidate measures illustrated in Figure 4-1, using travel demand models introduces the potential to project how travelers will modify their behavior in response to service changes. In part because of the origins of travel demand models in projecting the need for highway facilities, their representations of public transit systems are often basic, relying on generalized representations of level of service and simplified spatial representations.

One transit-focused travel forecasting model is FTA's Simplified Trips-on-Project Software (STOPS). STOPS is a simplified regional travel demand modeling framework developed to estimate the number of transit passenger trips that will use and benefit from a public transit project. It combines data from multiple sources and must be calibrated for use in a specific region. Importantly, it uses GTFS feeds to represent public transit routes and schedules. It has also undergone multiple major updates in a relatively short period of time. For example, the initial version of STOPS focused on estimating ridership on fixed-guideway modes but has been updated to include the ability to forecast all transit ridership, including local bus. Because of the rapid evolution of this software, it is highly recommended that any potential user begin by contacting FTA to access the most recent version of STOPS (https://www.transit.dot.gov/funding/grant-programs/capital-investments/stops). FTA is planning other related software releases, including separating the STOPS path builder so that public transit path attributes (e.g., travel time, waiting time, number of transfers) can be directly associated with transit rider survey records.

STOPS performs many of the same computations of transit level of service, mode choice, and assignment that are common in other trip-based models. Specifically, STOPS creates a zone-to-zone matrix of person trips stratified by automobile ownership and trip purpose across all travel modes. These trips are then divided for each travel mode under consideration using a nested logit mode choice model. Once the transit trip tables are prepared, STOPS assigns each to the facilities coded into the local network being evaluated (e.g., bus routes, stations, stops) to determine line-specific transit volumes.

Some of the most significant differences between STOPS and other conventional trip-based models include the following:

- STOPS model parameters have been calibrated and validated to replicate ridership on approximately 25 completed Capital Investment Grant (CIG) projects nationwide. This national calibration substantiates that the STOPS platform can generally replicate observed ridership for CIG projects across many different regional contexts.
- Conventional trip-based models use complex trip generation and trip distribution modules to develop origin-destination travel estimates. STOPS instead relies on census or local transit rider survey data for this information. This approach eliminates the need to calibrate the generation

and distribution modules, often shortening the time for model preparation prior to application.

- STOPS allows the user to directly input the regional transit trip table from a collected transit onboard rider survey. STOPS then uses the observed trip table for the existing conditions. In traditional travel forecasting methods, the development of the resulting transit trip table requires the joint calibration of trip distribution and mode choice models. This process typically takes months and often struggles to mimic the observed transit flows in a region.
- STOPS uses transit provider timetables in an expanded GTFS format to derive transit level of service information. The expanded format is necessary to capture drive-to-transit paths (including park-and-ride and passenger drop-off). This approach saves on network coding effort and significantly improves the accuracy of the transit system representation. This approach reduces the intense labor required to maintain high-quality, accurate transit networks within traditional travel demand models.
- Using transit count data, including system-wide unlinked trips and passenger boardings by route and station, STOPS adjusts itself to reflect the local, current conditions of the study area. If local agencies have access to linked transit trips by auto ownership and trip purpose, as is the case when a high-quality transit rider survey is available, STOPS can accept this detail as well and use it to further refine the understanding of local transit markets.

STOPS builds upon the earlier measures and data described in this report by allowing travel demand to shift in response to service changes. Specifically, STOPS can quantify expected mode and transit path shifts in response to services changes. In response to service cuts, travelers might switch to non-transit modes. In response to service improvements, more people might choose to take transit. STOPS allows the user to identify travel behavior changes due to public transit service changes. These changes can subsequently be used to calculate changes in trip characteristics.

A typical STOPS run generates three types of ridership estimates:

- **Current year** – using existing transit service and current year population and employment estimates for calibration purposes
- **No-build** – using the base level of transit (could be current year or a future year before a specific project improvement is introduced) and corresponding population and employment
- **Build** – using the no-build transit network as a base with proposed service changes added in/removed and population and employment estimates corresponding to the no-build

Figure 4-12 shows the overview of a STOPS application for both a current year scenario and a forecast year (or horizon year) scenario. The key difference between each is the population and employment estimates used. In the current year scenario, current population and employment estimates are used. When evaluating a horizon year, forecast estimates are used. For purposes of equity analysis as described in this report, either of these applications could be suitable depending on the service improvements being evaluated.[10]

The STOPS application highlighted in this report is focused on assessing user benefits in the context of a transportation equity analysis. It is unlikely that an agency would calibrate a STOPS application solely for this purpose. If a transportation agency finds cause to use STOPS to predict changes in transit ridership, they might also use it to assess changes in user benefits. These results might help local decision-makers examine the impacts of different transit alternatives under consideration. An appropriate analyst could subsequently use the sociodemographic information available from a high-quality transit rider survey to disaggregate calculated zone-to-zone user benefits into different population groups, as in this report.

When service changes that do not involve major capital expenditures are evaluated (e.g., bus network redesigns), current year applications would be most appropriate as such changes occur over a short period of time. For projects implemented over a long term, such as the introduction of a new fixed guideway, the example shown in Figure 4-12 for both a current year and a horizon year application is appropriate. The key is understanding what service change is being evaluated, which informs whether to hold the population and employment constant or to consider forecasted future year population and employment. The information available from STOPS or other travel forecasting tools can greatly enhance reporting of equity impacts with the opportunity to measure changes in behavior in response to clearly defined system changes. However, it is important for users to understand the techniques and appropriateness of such tools for a given policy goal.

[10] At the time of this writing, STOPS has not been used for a formal Title VI transit service equity analysis. Therefore, FTA has not been in a position to approve the use of STOPS for this purpose.

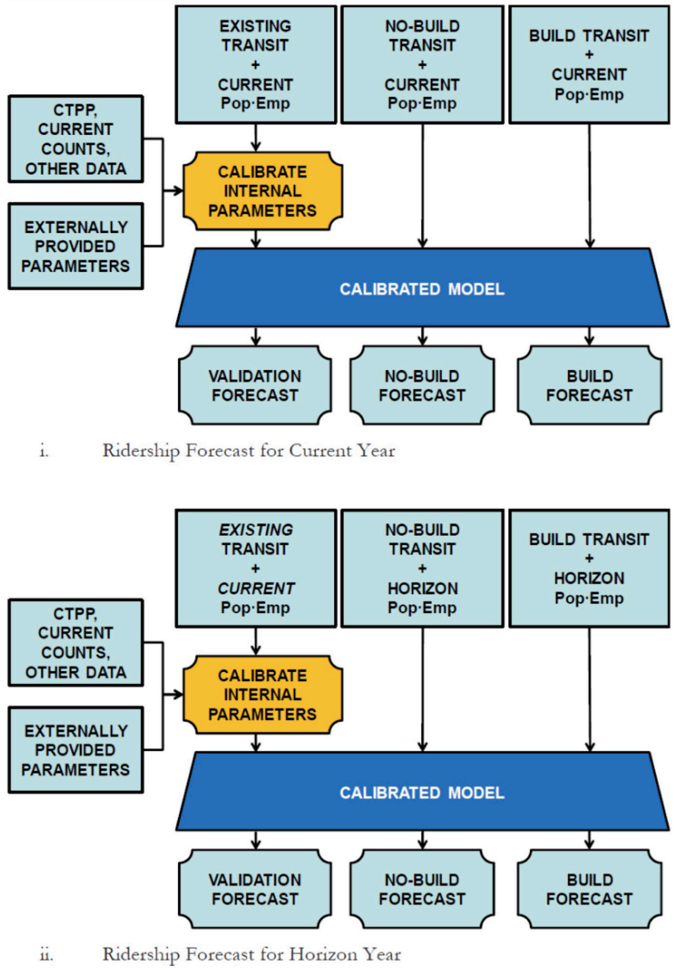


Figure 4-12 *STOPS application flowchart*

Source: Resource Systems Group [143, p. 7]

The STOPS software must first be calibrated for the specific location under study. STOPS runs in either "synthetic" or "incremental" mode depending on the calibration data used. These data come from either the Census Transportation Planning Package (CTPP) or transit rider survey data, if available. STOPS synthetic relies on CTPP, while STOPS incremental uses rider survey data.

In addition to software and input data, appropriately trained staff are essential for successful STOPS implementation. Although not as sophisticated as other regional travel demand models in use today, STOPS requires an understanding of the basic concepts of travel demand and the implications of proper calibration and use. The National Transit Institute provides periodic training for public sector users at no cost. It is highly recommended that any agency interested in using STOPS for capital and service planning invest time in training to ensure the tool is applied correctly.

One key advantage of using STOPS to assess the impacts of a service change is that it facilitates calculating one of the most theoretically appealing approaches to accessibility measurement. Specifically, the denominator of choice models that take a multinomial logit form can be interpreted as a measure of accessibility [15, 144]. This denominator is known as a "logsum" or "composite utility" because it is the logarithm of the sum of utility—or attractiveness—associated with all available choices. Candidate models include mode choice, location choice, destination choice, or any category of models that consider joint decisions (e.g., joint location-mode choice models). As the freedom to choose expands, logsums increase.

Changes in logsums between scenarios represent "user benefits" or changes in total travel impedance experienced by all travelers in a metropolitan area. They are expressed in terms of minutes of transit in-vehicle time but represent all components of public transit travel time, including waiting time, walking time, drive-access time, and transfers. Fares can also be included in the impedance calculations. Within STOPS, user benefits are computed using output from the mode choice model for each zone-to-zone interchange in the region. Differences in logsums between scenarios are multiplied by the number of travelers experiencing the change to produce summary measures of changes in the total "cost" of travel.

These approaches have the advantage of including characteristics of the levels of service provided by all modes available to make a particular trip (whether or not a mode is used), the attractiveness of opportunities available at a destination, and individual socioeconomic characteristics. In other words, they allow apparent accessibility to vary across individuals, depending on the particular choices they face and how they value the different characteristics of each alternative.

A simple example is helpful to illustrate why logsums are useful. Consider an existing zone-to-zone walk-to-bus path that entails a total travel time (walk from origin to transit stop, wait, in-vehicle time, walk to destination) of 40 minutes. In a build scenario, the in-vehicle time is reduced by 10 minutes. A person who has this choice available would enjoy an individual user benefit of 10 minutes. Logsums provide a way to rate the attractiveness of all alternatives; they consider that different aspects of each mode are likely to carry different values to different users. Simply looking at changes in door-to-door travel times, for example, would not consider that reductions in waiting or walking time tend to be more highly valued by users. Nor would they consider the benefit a user derives from having a premium mode or different access modes available for a trip. Logsums can take all characteristics of the alternatives into account and express changes in those characteristics in common units (commonly either dollars or minutes). They can be decomposed and summed for different user groups. This means that they are much more suitable for evaluating the costs and benefits of alternatives that entail changes across a variety of aspects of transit service. Logsum-based user benefit calculations are, however, relatively rare in transit planning practice in part because their results can be difficult to communicate to a non-technical audience.

Prior to STOPS, FTA developed software called Summit and encouraged transit agencies to use it when evaluating CIG project requests. Summit is not a stand-alone model and must be integrated with local agency travel forecasting models or STOPS in order to be used. However, once integrated, Summit outputs measures of "user benefits" that rely upon changes in mode choice logsums.

In Summit, user benefits are measures of changes in the composite "price" of travel between two scenarios. In a STOPS + Summit workflow, these changes in price primarily occur because of changes in travel times due to changes in public transit service. In principle, price can also change because of fare changes, although as of early 2020 fare modeling within STOPS is in its early stages. User benefits based on changes in the price of travel have several advantages over straightforward measures of travel time savings, such as those computed using transit rider survey and CTPP data above, and include:

- Non-transit-users and those who switch to public transit are included.
- Benefits are described in equivalent minutes of travel time and can be summed and decomposed across groups and geographic locations.
- Theory is undergirded by the concept of "consumer surplus" that recognizes some users would be willing to make the same choice at a higher price of travel.

To accurately measure the impacts of a particular service change, performance is compared between no-build and build networks. Summit reports user benefits of zone-to-zone equivalent minutes segmented by trip purpose and socioeconomic status. Although Summit seems complex, the idea of changes in minutes of time for a particular trip purpose or socioeconomic group under a given transit system change is easily understood. Summit results can be mapped to show areas experiencing travel time savings, where benefits or improvements are generally shown in green and disbenefits or areas where travelers experience worsening options are shown in red. Summit also outputs additional summaries of changes in trips and travel conditions that can be used for further analysis.

The general workflow for integrating Summit and STOPS is as follows (interested users are again encouraged to contact FTA for assistance):

1) Execute STOPS with an appropriate override file in place that will direct the software to output binary files that can be read by Summit.

2) Copy output from STOPS to a directory containing all required Summit files (control files, Summit executable, and a utility that edits filenames so they can be read by Summit).

3) Execute a batch file to run Summit and view relevant outputs including report files for each trip purpose (with filetype extension .rpt) and row and column sums showing results for individual production and attraction zones (with filetype extension .rcs).

4) Join .rcs file output with a spatial layer representing the zones and visualize the results.

Example Application

Working with FTA, the project team prepared a STOPS model to assess the impact of System Reimagining on public transit ridership. Fortunately, FTA staff had already prepared a STOPS incremental calibration using the 2017 rider survey data. The team used a GTFS feed provided by FTA to represent the level of service consistent with the rider survey. This combination served as “existing” data. The same GTFS feeds as above were then used to represent the before and after System Reimagining to represent the no-build and build conditions, respectively.

Note that this STOPS configuration is different from how the program typically operates. More commonly, the existing and no-build conditions are the same and the effect of a single project (e.g., a new fixed guideway) is modeled as the build condition. This type of STOPS run yields a much cleaner interpretation—all changes observed are due to the introduction of one project. In the case of System Reimagining, the entire network was changed overnight, meaning that the results will reverberate across the entire service area.

The team also integrated Summit into the STOPS workflow to calculate user benefits resulting from the network redesign. Herein is reported a subset of possible results—overall user benefits summarized using thematic maps at the zone level for both home-based work and home-based other trip purposes. Using these two trip purposes will facilitate a more comprehensive look at System Reimagining’s impacts.

Figure 4-13 includes four thematic maps illustrating user benefits extracted from Summit’s “Table 5” covering all transit access markets (walk to transit, park-and-ride, and kiss-and-ride) for two trip purposes separately for productions and attractions. As expected, the results show substantial spatial variation across the service area. Key network redesign strategies involve consolidating stops and routes to improve reliability and travel times and eliminate network redundancy. Stop consolidation in particular would result in a checkerboard effect, where adjacent zones experience benefits and costs depending on whether stops were removed. Uniform changes along a route (e.g., an entirely new route or a route elimination) would result in spatially clustered changes along the relevant alignment. In all cases, larger numbers of potential users experiencing the change will result in greater magnitudes of user benefits, all else being equal.

System Reimagining's effect on user benefits (both positive and negative) appears to be concentrated away from the center of the service area. Both trip productions and attractions located in downtown Houston and surrounding areas experienced little change in user benefits, meaning that there was little change in terms of travel conditions for users originating or destined for those locations. For home-based work trips, positive user benefits are concentrated in the north service area for both productions and attractions. This result is consistent with METRO's own analyses. In *Reimagined 5-Year Transit Service Plan*, the agency summarizes expected travel time changes from various locations throughout the service area [145]. By far the location with the greatest expected changes both as an origin and destination is the northernmost point in the network, likely due to new concentrations of high-frequency service there, especially during the peak period [146]. Travelers originating in the northeast portion of the service area appear to fare worst after the service change. Side-by-side comparisons of the before and after service maps reveal that frequencies are likely reduced in those locations. On net, user benefits after the service change for home-based work trips (evaluated with the peak-period transit system) decrease by approximately 900 hours.

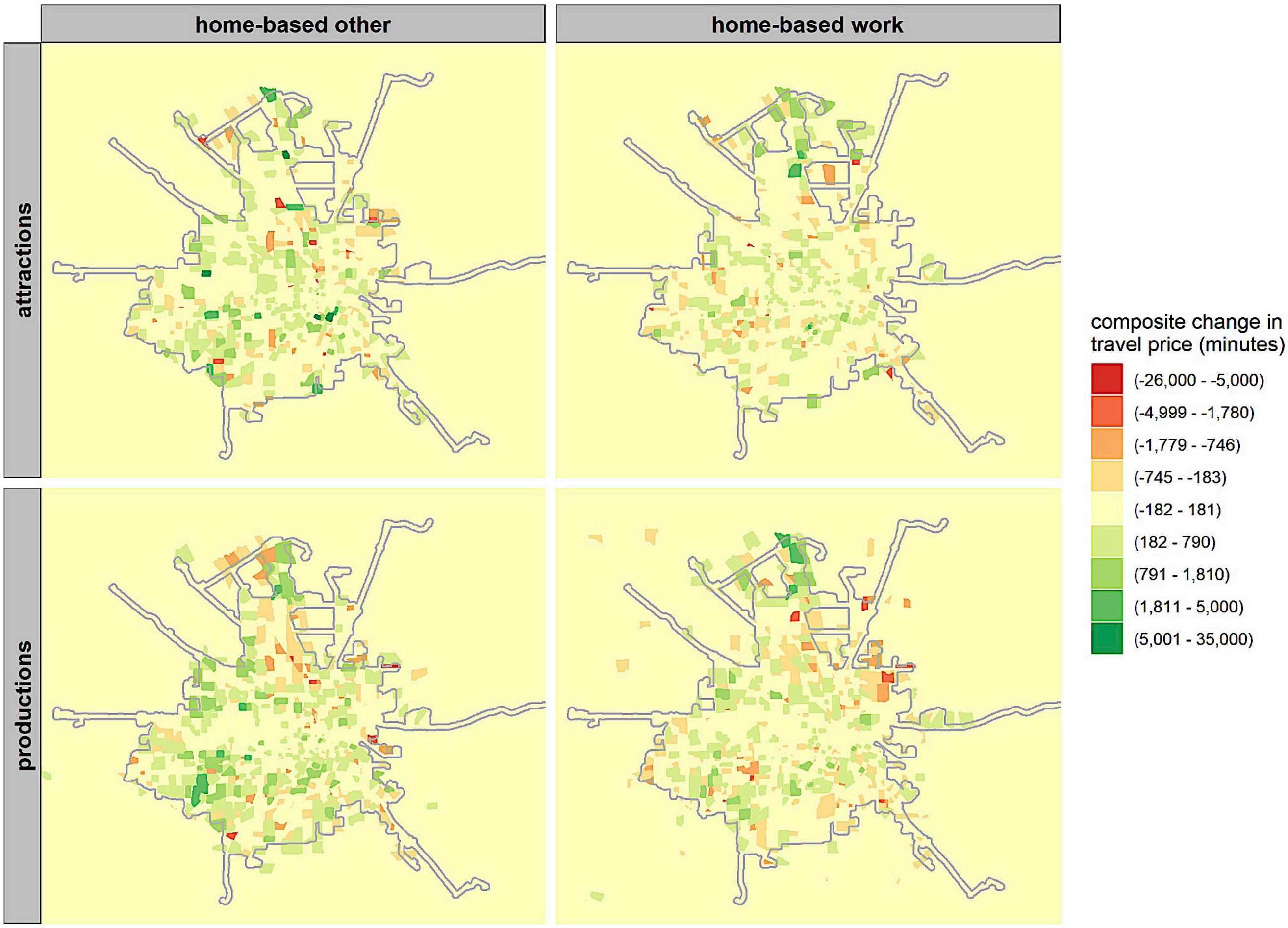


Figure 4-13 *Weekday user benefits resulting from System Reimagining calculated using STOPS and Summit for all users*

Note: Houston METRO service area (1/4 mile around bus stops and 1/2 mile around rail stations) combined to reflect both the before and after conditions shown in grey.

Positive user benefits for home-based other trips appear to be concentrated in the southwest of the service area for both productions and attractions. This is where much of the new frequent service was concentrated; clearly these service increases align well with the trip-making needs of users beginning or ending trips in those locations. On net, the user benefits for home-based other trips (evaluated with off-peak transit system) are positive and equal to 839 hours. The differences in the sign of overall user benefits between home-based work and home-based other trips indicates in part the tradeoffs faced by the SR designers. In order to provide better service aligned to non-work travel, service with a commute orientation was reduced.

With some manipulation of the underlying trip tables, a STOPS incremental run can be configured to produce user benefits estimates for different demographic groups. Because capacity constraints are not modeled in STOPS and transit networks do not experience congestion, segments of the transit trip table can be extracted and used as inputs in separate model runs. Figure 4-14 summarizes changes in user benefits for people of color and Figure 4-15 shows the same result for White users. While Figure 4-14 largely resembles Figure 4-13 because public transit users in Houston are overwhelmingly people of color (approximately 78% as of 2017 [93]), there are some differences. Notably, changes in user benefits appear to be more negative in the northeast when looking at people of color alone and focusing on trip productions. This result suggests that the travel patterns of some White travelers are better aligned with the proposed service changes there and they are offsetting the negative changes observed in Figure 4-14. Figure 4-15 shows the same user benefit calculations for White travelers and shows fewer well-defined clusters of costs and benefits. Zones that experience net benefits (dark green) are more numerous in Figure 4-15 compared to Figure 4-14. Further tabular comparisons can be made of total user benefits for each group for each trip purpose.

Figure 4-14 *Weekday user benefits resulting from System Reimagining calculated using STOPS and Summit for people of color users*

Note: Houston METRO service area (1/4 mile around bus stops and 1/2 mile around rail stations) combined to reflect both the before and after conditions shown in grey.

Figure 4-15 *Weekday user benefits resulting from System Reimagining calculated using STOPS and Summit for White users*

Note: Houston METRO service area (1/4 mile around bus stops and 1/2 mile around rail stations) combined to reflect both the before and after conditions shown in grey.

Strengths and Limitations

Using logsums as a proxy for user benefits is attractive because they consider the full scope of available modes, levels of service, and individual characteristics when assessing accessibility at a point in time or changes over time. This property means that the analyst does not have to make arbitrary choices regarding travel time thresholds or destinations of interest. Information about revealed behavior is simply used to assess the tradeoffs travelers make between the properties of competing modes given their socioeconomic conditions and other factors. Importantly for analyses of public transit systems, logsums provide for a measure of benefit even if a user does not avail themselves of a particular option, since their expanded choice set is considered to be of value.

How to Choose the Right Measure(s) for Your Community

The performance measures summarized above all emphasize different aspects of public transit and make different assumptions about what users value and what principles should guide decision-making related to accessibility and equity. It should be clear that there is no silver bullet; no single analysis can be conducted that will definitively state that a policy or plan will or will not be acceptable from an equity perspective. As demonstrated in Section 3 of this report, local data and local perspectives are vitally important to support and supplement any quantitative or spatial analysis of public transit system performance.

With this caveat in mind, it is possible to make general comparisons across the different performance measures summarized and to make some judgments about their appropriateness. As the literature and practice review (Appendix A) both demonstrate, the use of access to opportunities measures is relatively well developed. Nationwide assessments of cumulative opportunities accessibility are readily available and proprietary tools have come online that facilitate the calculation of accessibilities with relatively high spatial and temporal precision.

Considering the desirability of a tiered analysis, and the relative dominance of the access to opportunities approach, the following hierarchy is proposed for use by public transit agencies seeking to assess how well their transit systems connect people to opportunities under current and future scenarios:[11]

1) Agencies with access to a recent and high-quality onboard transit rider survey should use that survey to assess existing travel patterns by demographic group and to consider the effects of service changes on existing riders by calculating at least trip characteristics. This is consistent with existing approaches used in FTA's required service equity analysis.

    a) If possible, effects of service changes on new riders should also be assessed, using STOPS or another appropriate travel modeling tool. Changes in the composite price of travel (i.e., logsums) can be a powerful tool for assessing service change impacts.

2) Agencies with no recent onboard survey data can:

    a) employ an access to opportunities approach that considers how these measures change under different scenarios (they might also incorporate origin-destination flows by mode using CTPP or

[11] Agencies should consult with FTA before applying these methods, since not all are approved for service equity analysis.

similar datasets to identify OD pairs with relatively strong transit demand), or

b) consider a geographic proximity-based approach that does not consider actual changes in door-to-door transit service, but only considers the qualitative nature of a transit service change (i.e., positive/negative) and populations living proximate to stations and stops, consistent with existing approaches used in FTA's required service equity analysis.

Precisely what can be gleaned from each of these use cases and whether and under what conditions the results will meaningfully differ is not currently known, outside of relatively limited investigations [e.g., 4]. The results presented above, with the effects of the same service change evaluated using a suite of different metrics, are some of the first of their kind and can be used to aid agencies seeking to identify meaningful performance measures relevant to their local conditions. Agencies seeking to apply public transit performance measures should also consider the limitations of prevailing access to opportunities approaches and the importance of understanding the travel patterns of current public transit users.

Limitations of Cumulative Opportunities Measures

Despite the widespread popularity and mass appeal of cumulative opportunities measures and isochrones, they embody major limitations for understanding infrastructure and policy impacts that are scarcely acknowledged in the literature or in practice. These include:

- **Limited utility for assessing regional benefits.** Isochrone maps can show the number of destinations that can be reached from any origin location in a region. These types of maps are useful for individuals and businesses seeking to understand how a change in transit service will affect their ability to reach opportunities or customers [e.g., 24]. But as the number of origins of interest grows to cover an entire region, it is unclear how to best aggregate isochrones to determine the magnitude of a regional benefit.
- **No integration of public transit market information.** The limited utility of a regional benefit analysis based on access to opportunities arises in part because of the absence of information about the public transit market. It is entirely possible to imagine a scenario where apparent freedom increases substantially for large numbers of people because of a proposed capital improvement or service change but where the actual/future transit market is quite weak. If such an investment or change is pursued on the grounds that it will increase freedom, it could ultimately perform worse in terms of helping people reach destinations they need by public transit than a comparable change whose apparent access to opportunities benefit is smaller.

- **Ignorance of demographic change.** One purported benefit of access to opportunities measures is that they represent the ideal goal for public transit systems (i.e., increasing freedom). But as the literature has demonstrated over time, increasing public transit accessibility can lead to near-term demographic changes as increasing accessibility gets capitalized into property values [147–149]. Further, states, MPOs, and transit agencies are ill-equipped to understand small-scale demographic changes [150]. These combined findings mean that even with appropriate analytical techniques that apportion benefits to different groups, any future-oriented analyses will likely misidentify the beneficiaries of transit system changes.

Importance of Understanding Current Public Transit Users and Their Travel Patterns

In order to understand public transit system performance, one must have a well-developed understanding of current public transit users and their travel patterns. This basic analysis is surprisingly absent from contemporary transit performance analyses, despite the historical importance of assessing quantities such as travel time changes and changes in utility/consumer welfare across planning practice [e.g., 144, 151].

This absence is partly due to the withering criticism leveled at such measures from various sources. Without exception, these sources argue for access to opportunities approaches without acknowledging any of their inherent limitations. For example, Pereira et al. [9] highlight the important role of constraints that exist outside of individual/household control. It is these constraints (e.g., residential location, income, family structure, mandatory activity locations) that interact with preferences to determine revealed travel behavior outcomes. They argue further that revealed behaviors that seem to indicate disadvantage (e.g., long commute distances) can only be considered problematic to the extent that they arise because of constraints.

Martens and Golub [152] and Pereira et al. [9] both argue that analyzing opportunities is more important than analyzing observed choices. They maintain that the current travel patterns of an individual are likely to shift over time as the locations of their family, friends, and mandatory activity locations also shift. Walker makes the point even more strongly, asking:

> When you went shopping at a particular store, does it matter that you *could have* gone shopping somewhere else, or shopped online while in bed, or embraced an ascetic spiritual path of buying as little as possible? A study of freedom would be intensely interested in that, while conventional planning would merely record what you did and use that to predict what you, despite your illusion of freedom, will continue to do. [153, p. 125; emphasis in the original]

Each of these lines of thought misapprehends the nature of planning-related analysis and falls prey to the individualistic nature of the isochrone. When assessing the performance of a metropolitan transportation plan, outcomes for *individuals* are not of specific concern in an aggregate analysis. Instead, analysts aggregate results over population groups, places, or the entire region to determine performance. Even though an individual's travel patterns will likely change as circumstances change, including many different people and their (revealed) travel within a single performance measure ensures that the measures capture these variations in behavior. For the same reason, travel surveys collected on a single day are used to estimate regional travel demand models. Even though individual travel patterns change from day to day, a random sample of individuals drawn for a single day will reproduce regional travel patterns in all their complexity.

The notion of constraints versus preferences is important but can also be thoughtfully addressed. One simply needs to determine appropriate criteria that can be used to home in on the group of interest. It has long been understood that some public transit users have no option but to use public transit while others freely choose to use it [1, 154]. Other work has differentiated between car-less (constrained) and car-free (choice) households using responses to attitudinal questions on a household activity survey [155]. That work has demonstrated both socioeconomic as well as travel behavioral differences between households that choose to not have a vehicle and those that wish to but cannot. Simply grouping all zero-vehicle households or all public transit users together to calculate performance measures is inappropriate, but with care, relatively homogeneous groups can be identified and their characteristics studied.

Another argument against revealed behavior measures is that they do not consider foregone trips or travel demand that might be suppressed [9, 156, 157]. This is also a fair point; given different circumstances, individuals facing transportation-related constraints would be likely to make different decisions. But this is where near-term (run either for the current year or one to five years from the present) travel models can play an important role. The effects of changes in level of service on various modes or changes in socioeconomic conditions can be simulated. What if all low-income households were suddenly given cars? What if local bus service suddenly became more attractive? How would these changes shift travel patterns and reveal potentially suppressed demand? At the end of the day, individuals have to make decisions about where to travel and when.

In addition to these critiques, there are real challenges associated with collecting revealed behavior data. Cost is a key factor. Obtaining high-quality, statistically controlled transit rider survey data can be expensive. A completed survey record can cost upwards of $50 when costs associated with survey design, data collection, cleaning, and expansion are considered [158]. Other issues that plague transportation data collection, such as survey fatigue, are less relevant here since prospective survey respondents can easily be found on transit vehicles as well as at stops and stations. Nevertheless, transit rider survey data collection methods continue to advance, and such data collection is mandated by FTA for large public transit agencies, as discussed in Section 2.

There are also two major benefits associated with using people-focused near-term analyses. The first is that members of the public and transportation equity advocates appear to be quite interested in how transportation infrastructure investments and policy choices will affect the traveling public given their current travel patterns. From the perspective of these advocates, there are inequities baked into the current system. These are reflected in racial and class differences in terms of mode share, level of service, exposure to pollution, noise, and other externalities of transport [39]. Without an understanding of *current* inequities, the thinking goes, transport policy and infrastructure decision-making cannot be expected to mitigate them. The second is that near-term analyses mitigate many of the shortcomings known about long-range forecasting. The difficulty of projecting future land use characteristics and demographics, for example, is not at all relevant when conducting near-term analyses since those characteristics can reasonably be expected to be similar to those that prevail today. Further, a near-term forecast can supplement and inform long-range efforts by providing valuable comparative information about future-year uncertainties.

Near-term forecasts are also required by FTA for Capital Investment Grant (CIG) applications. STOPS is one approach that CIG applicants can use to prepare the required forecast [159]. Making near-term instead of long-term projections brings with it multiple benefits.

In describing their use of current-year forecasts, FTA states:

> "..." project evaluation based on existing conditions provides the most easily understood, most reliable, and most readily available information for decision-making…Use of current year data increases the reliability of the projected future performance of the proposed project by avoiding reliance on future population, employment, and transit service levels that are themselves forecasts. [159]

Hypothetical Example Comparing Access to Opportunities and Transit Use

To demonstrate some of the fundamental concerns that arise when using access to opportunities measures, a simple three-zone example region is employed here consisting of a central business district (CBD) (Zone 1) containing mostly jobs and some population and two "suburban" districts (Zones 2 and 3) containing mostly population and some jobs. All travel-related characteristics of the scenarios are summarized in Table 4-7. Note that the table represents all home-based work travel occurring over a 24-hour period, and trips are summarized in origin-destination, as opposed to production-attraction format. This means that the 100 trips from Zone 2 to 1 in the morning occur in the reverse direction in the evening and thus appear on two separate rows in the table. Two base cases are presented in Table 4-7:

- **Base 1** is characterized by equal travel times between all OD pairs (100 minutes) and a distinctively CBD-oriented travel pattern, with most trips occurring between the CBD and Zones 2 and 3. There are comparatively fewer trips occurring between Zones 2 and 3.
- **Base 2** balances travel demand across the region so that both travel times and trip counts are symmetrical. Traveling between each OD pair takes 100 minutes and there are 100 trips occurring between each pair throughout the day.

In addition to these base cases, there are two alternatives to Base 1 and one alternative to Base 2:

- **Alt 1-1** differs from Base 1 with a 50% reduction in suburb-to-suburb travel time. Travel time between Zones 2 and 3 is reduced to 50 minutes. Multiplying the affected number of trips (100) by the reduction leads to a total travel time savings of 83.3 hours in this alternative.
- **Alt 1-2** differs from Base 1 with a 50% reduction in suburb-to-CBD travel between zones 1 and 2. Travel time between zones 1 and 2 is reduced to 50 minutes. In this case, more trips are affected (200 as opposed to 100) so the total travel time savings are 166.7 hours.
- **Alt 2-1** also improves suburb-to-suburb travel, but from Base 2 where there is greater travel demand between suburban locations. In this case, the total travel time savings is identical to that shown for Alt 1-2 since the same number of trips are affected by the same travel time improvements.

Importantly, under reasonable assumptions, an access to opportunities approach would show no difference between any of these alternatives and would thus be unhelpful in choosing between them. If a cumulative opportunities threshold of 100 minutes was selected, all of the zones would have identical performance. All jobs would be reachable from all origins, so accessible cumulative opportunities would be 1,200 for each of the three zones. A corollary of this finding is that projects will not have any effect on cumulative opportunities unless they reduce travel times below the threshold value. If travel times between pairs in a dense urban area are already below the threshold, any projects or service changes that improve travel times will only show improved accessibility to the extent they make trips involving transfers more attractive. If most of the reachable destinations from an origin are already accessible within the threshold, gains from the project will appear minimal unless demand is explicitly accounted for.

Counterintuitive results can also emerge from an approach based on access to opportunities. In the case of Alt 2-1, for example, an access to opportunities approach with an appropriately scaled threshold would suggest only modest gains from improving suburb-to-suburb travel times. But examining existing patterns of transit ridership clearly demonstrates that an important market for public transit exists in that corridor. Although the example is admittedly stylized, the broader point is that fully understanding the impacts of a transit project must involve an analysis of *current* transit markets, ideally supported by an up-to-date and high-quality transit rider survey. Extensions to the basic analysis conducted here could involve looking at specific times of day, trip purposes, and demographic groups.

To reiterate, explicitly accounting for current travel demand allows an analyst to scale and tailor an assessment of project impacts relative to current travel patterns. If a demand-agnostic approach is used instead, results can be counterintuitive in the best case and misleading in the worst.

Table 4-7 *Example Hypothetical Base Cases and Alternative Public Transit Scenarios for a Three-Zone Region*

	Base 1	Alt 1-1	Alt 1-2	Base 2	Alt 2-1
Population					
Zone 1	100	100	100	100	100
Zone 2	1000	1000	1000	1000	1000
Zone 3	1000	1000	1000	1000	1000
Jobs					
Zone 1	1000	1000	1000	1000	1000
Zone 2	100	100	100	100	100
Zone 3	100	100	100	100	100
Door-to-door Travel Times, Minutes					
1 to 2	100	100	**50**	100	100
1 to 3	100	100	100	100	100
2 to 1	100	100	**50**	100	100
2 to 3	100	**50**	100	100	**50**
3 to 1	100	100	100	100	100
3 to 2	100	**50**	100	100	**50**

Table 4-7 (cont.) *Example Hypothetical Base Cases and Alternative Public Transit Scenarios for a Three-Zone Region*

	Base 1	Alt 1-1	Alt 1-2	Base 2	Alt 2-1
Origin-Destination Trips					
1 to 2	100	100	100	100	100
1 to 3	100	100	100	100	100
2 to 1	100	100	100	100	100
2 to 3	50	50	50	**100**	**100**
3 to 1	100	100	100	100	100
3 to 2	50	50	50	**100**	**100**
Total Travel Time, Hours					
1 to 2	166.7	166.7	**83.3**	166.7	166.7
1 to 3	166.7	166.7	166.7	166.7	166.7
2 to 1	166.7	166.7	**83.3**	166.7	166.7
2 to 3	83.3	**41.7**	83.3	166.7	**83.3**
3 to 1	166.7	166.7	166.7	166.7	166.7
3 to 2	83.3	**41.7**	83.3	166.7	**83.3**
Total Travel Time Saved, Hours					
To Zone 1	--	0.0	83.3	--	0.0
To Zone 2	--	41.7	83.3	--	83.3
To Zone 3	--	41.7	0.0	--	83.3
All	--	83.3	166.7	--	166.7

Note: Changes from the base alternative in each case are shown in bold red text.

Outstanding Considerations

It was not possible to pursue all equity-related data sources, approaches, and strategies throughout the course of this work. The research team was limited in their ability to access and assess certain proprietary data sources and analysis considerations, as discussed further below.

Anonymous Location Data

Anonymized human movement data are available for purchase from multiple vendors. In principle, these data can be combined with information on public transit level of service to generate measures of trip characteristics. But in practice, the data embody many limitations that must be fully appreciated prior to their application. Understanding precisely what products and services each vendor offers is somewhat difficult; since all are private companies competing with one another, there is no central repository documenting precisely what each provides. In general, to obtain these data, you must contact one of the vendors and discuss your specific needs. They will negotiate on the particular terms of payment and data formats. This was not employed as part of this work because of budget constraints.

There are several prominent movement data vendors with varying approaches. One supplier repackages data generated by two of the largest cellular service providers in the United States. The data use unique identifiers associated with individual cell phones to triangulate cell phone locations (with a resolution of about 50 meters) over time. Locations where phones appear to stay overnight are identified as home locations and other locations where phones linger for extended periods of time are identified as destinations.

This approach differs from using Global Positioning System (GPS) data gleaned from mobile devices. Origin-destination paths can subsequently be inferred from this mass of information and packaged at arbitrary geographic and temporal scales (e.g., tract-tract flows during the PM peak period) for specific trip purposes (including home-based work, home-based other, and non-home based). At each step, vendors seek to protect individual cell users' privacy. No speed, modal, or route information is available, so the data are best understood as providing a raw sense of overall travel demand. Demographic information, including age, sex, and income levels, can also be created by data providers and included with delivered datasets, but their provenance is less well documented and would certainly have to be created using completely synthetic methods.

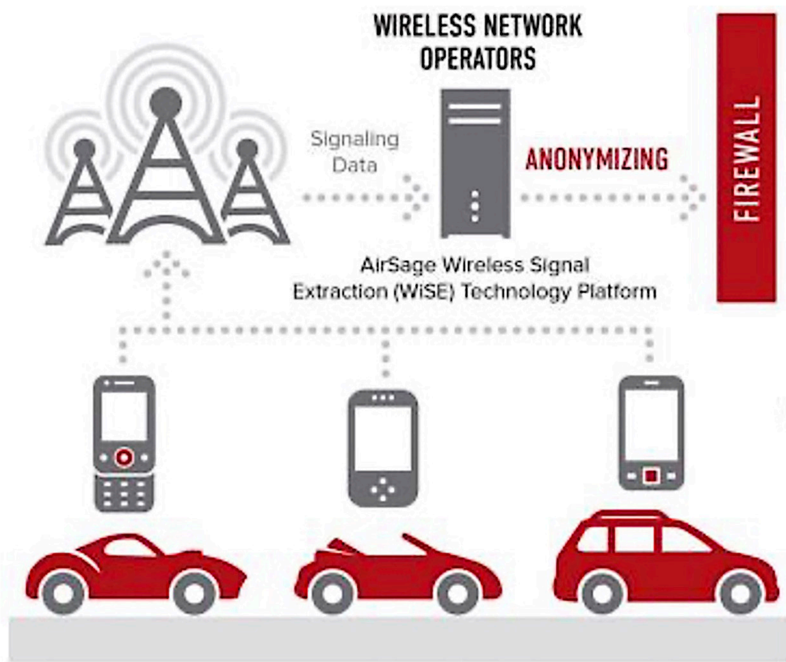


Figure 4-16 *Data vendor processing steps*
Source: https://perma.cc/LPV8-AJ66

Another company takes the approach of combining information from multiple sources, including vehicle data, anonymous cell trace data, location services from multiple smartphone apps, and GPS data from navigation service vendors.[12] These data are processed using proprietary algorithms. This processing step means that it is not possible to independently verify trip data produced by the vendor. Recognizing that most data sources focus on and best represent automobile travel, vendors are working to develop more multimodal products.

Yet another product claims to have integrated cell trace data with multiple other sources and statistical modeling to create "the first comprehensive understanding of movement in America."[13] They note that they employ "a proprietary optimization process" combining data from different sources including smartphone and vehicle movement, travel demand models, and measured traffic counts. It is frequently the case that products' underlying methods cannot be subjected to peer review or otherwise independently verified.

Example Application

Each data vendor provides short documents demonstrating potential use cases for their data products. One describes projects including travel demand management and congestion mitigation in Virginia and congestion mitigation

[12] https://www.streetlightdata.com/population-mobility-technology [https://perma.cc/K2NZ-UR24].
[13] http://www.citilabs.com/software/streetlytics/ [https://perma.cc/K4G9-XP3F].

in Napa County, California. Both focus on identifying the origin locations of trips using specific facilities or passing through particular locations so that appropriate mitigations can be implemented. Neither of these examine how measures of accessibility or trip characteristics could be calculated or assessed.

Other academic work has examined the utility of anonymous location data for uncovering fundamental characteristics of human movement. For example, Calabrese et al. [160] develop and apply techniques that convert data gleaned from one million mobile phone users (raw data were obtained from one vendor) into an origin-destination matrix for the Boston metropolitan region. They compared their results to CTPP estimates of total commuting trips and found general agreement. Widhalm et al. [161] also focus on methods development, proposing approaches for extracting trip chains and classifying activities based on fusing land use information with cell phone data.

To date, no authors have applied anonymous location data to questions of accessibility. As demonstrated above, most prior work has emphasized identifying and characterizing aggregate travel behavior information. Mode-specific trip tables are often discussed but are not yet widely available or reliable. Such trip tables would be required to assess the impacts of public transit service changes, for example. If a public transit-specific OD table was created, then methods similar to those described for CTPP data could be employed. The failure to prioritize modal differentiation is likely due to the automobile's overwhelming dominance across most of the United States.

Strengths and Limitations

These data vendors offer an attractive value proposition by claiming a near-complete representation of existing travel demand at relatively low cost and almost no effort on the part of the purchaser. All vendors provide data at much less expense than that associated with a floating car study or traditional regional travel/activity survey. But of course, the data are simulated and aggregated from multiple sources and do not represent a census of the traveling population. Some scaling and weighting inevitably occurs. One vendor, for example, only receives data from two of the largest cellular providers. Accordingly, it must scale its flows up to ensure representation of total travel demand.

Because of the importance of cell phones as a raw data source across all vendors, disparities in cell phone ownership will be reflected in the final travel patterns each vendor creates. While aggregate totals may match independent data sources at relatively large spatial scales, results summarized for finer-grained geographies are likely to be suspect, especially if demographic summaries are desired.

Competitive Measures

Competitive measures of accessibility take the access to opportunities approaches one step further when considering travel demand. These measures were not calculated as part of this work because their full application requires assessing automobile level of service alongside that of public transit, which was outside the scope of this report.

Originally developed by Qing Shen [132, 133], competitive measures of accessibility consider not only the opportunities that can be reached from each origin location, but also other travelers who are trying to reach the same opportunities. In this way, locations with apparently high accessibility can have their performance diminished if there are other potential travelers located within an accessible distance. Accordingly, these measures are most useful for calculating accessibility to opportunities whose consumption would make them unavailable to others, such as employment. Travel by all modes can be considered, and the most sophisticated competitive measures consider travel by both automobile and public transit. In principle, non-motorized competition could also be included but would likely represent a small share of the overall competition in all but the densest metropolitan regions.

Conveniently, data needs are identical to regular access to opportunities approaches and include travel times between all OD pairs and the number of opportunities that are available at all destinations. The measure itself is calculated slightly differently than non-competitive access to opportunities. It is a fraction whose numerator is identical to a cumulative opportunities measure and whose denominator includes a kind of reverse accessibility, where all the people who can access the same destination are summed. Either hard thresholds or gravity factors can be used to weight both people and opportunities. If large numbers of people can get to the same opportunities, the accessibility experienced at an origin will be diminished.

To assess the outcomes of service changes using competitive measures, any of the methods described for access to opportunities measures can be used, including threshold-based approaches, population-weighting, or community identification.

Example Application

Competitive measures have been widely applied in the literature. For example, Merlin and Hu [131] compared several accessibility measures calculated for the Los Angeles metropolitan region to explain spatial variations in employment patterns. Importantly, they find spatial differences in the patterns of different accessibility measures (Figure 4-17) and identify a stronger connection between labor market outcomes and competitive measures. As shown in Figure 4-17, locations identified as high accessibility differ between competitive and cumulative opportunities. Specifically, downtown Los Angeles (shown in blue) has the highest cumulative opportunities accessibility, but also has many workers competing for those jobs. When this complete picture is taken into account, other more suburban locations in the metro region are highlighted as experiencing high accessibility to employment opportunities.

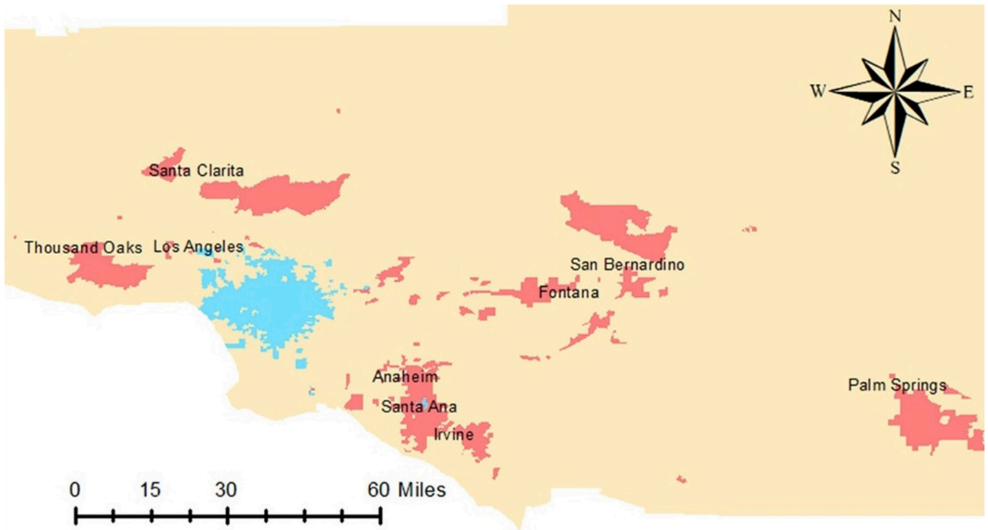


Figure 4-17 *Example application of competitive accessibility measures calculated in the Los Angeles metropolitan region*

Note: Blue areas represent high accessibility according to a regular gravity-based access to opportunities measure, while red areas represent locations of high accessibility according to competitive measures.

Source: Merlin and Hu [131, Figure 4]

These collected findings lead the authors to conclude that the limitations of cumulative opportunities measures make them inappropriate for explaining labor market outcomes. They highlight the utility and attractiveness of cumulative opportunities measures from a planning perspective because they are relatively easy to calculate, visualize, and interpret. But they raise questions regarding the appropriateness of using cumulative measures to explain the distribution of transportation system benefits. Similar results are reported by Bunel and Tovar [162], who performed a comparative assessment of different accessibility measures applied to the Paris, France, metropolitan region. They found that not accounting for the effects of competition can lead to overestimation of accessibility.

To assess the impacts of a service change equity analysis using competitive measures, the analyst would follow the steps identified for general access to opportunities approaches but would substitute competitive measures where appropriate.

Strengths and Limitations

The key strength of competitive measures is that they appear to have more explanatory power than cumulative measures when assessing employment outcomes. They are also more theoretically defensible for representing accessibility to job opportunities because the labor market is competitive, and one job can only be filled by one employee. Accordingly, competitive measures are the first discussed here that meaningfully consider travel demand by including the potential travel of others in a region.

The key weaknesses of competitive measures are that they are more difficult to calculate than cumulative opportunities measures, and the final metric is not as easily interpreted. They are also only applicable to employment opportunities, since accessibility to other opportunity types is not necessarily competitive. Other residents' access to a grocery store or healthcare facility does not diminish your ability to access the same location (but may lead to some diminished level of service if a high level of competition results in long wait times, for example).

People with Disabilities

Adequately incorporating the needs of people with disabilities into accessibility and equity analysis is an outstanding concern that was not possible to address within the scope of this work, given limitations in the existence and level of specificity of datasets. These issues were consistently raised by members of the Community Advisory Group (see Appendix B for further discussion) and must be addressed in future work as they directly bear on how relevant the Section 4 analysis results are for this group.

A number of academic studies have been conducted that examine the challenges that people with disabilities face when using or attempting to use public transit. These include a hostile built environment, transit system design that does not take their needs into account, and social conventions that lead to poor customer service [163, 164]. However, there is a gap regarding the first and last mile *physical* accessibility challenges faced by people with disabilities that are especially relevant when considering access to opportunities and trip characteristics. While transit stops, stations, and vehicles may be physically accessible according to ADA requirements, the pathway from a potential rider's origin or to their destination may be untraversable based on the individual's mobility situation because of sidewalk quality or physical obstructions. Data on these obstructions can be incorporated into any of the Section 4 spatial analysis methods using appropriate path-building techniques that exclude pedestrian paths with obstructions or connectivity gaps. But data on sidewalk conditions are rarely available. When they can be found, they are usually collected for a single jurisdiction using bespoke methods [e.g., 165]. Efforts to standardize and encourage the collection of sidewalk quality data would be of incredible value to move this understudied area forward.

Section 5 Conclusions

Public transit systems facilitate connections between people and the activities they need to undertake to live a meaningful life. The concept of accessibility—the ease with which destinations can be reached—captures this concept. There is much work yet to ensure that opportunities to use public transit to reach desired destinations as well as the destinations themselves are more equitably distributed across population groups and places in the United States.

Complete equality in public transit accessibility is not a realistic goal, since people and businesses have substantial choice in their location decisions and well-functioning land markets lead to price increases in areas where accessibility is high. Transportation equity refers to conditions in which no one is disproportionately disadvantaged by a lack of access to the transportation resources they need to live a meaningful life. Because of the limited options they usually face, combined with the legal traditions of civil rights and environmental justice in the United States, people of color and low-income people are often the focus of transportation equity-related efforts.

As this report demonstrates, transit agencies can undertake many different activities to advance transportation equity objectives in cooperation with knowledgeable local partners. Section 3 covered different procedural and planning practices that agencies have used to articulate and advance equity-related goals. Section 4 and its supporting open-source software resources demonstrated how data and quantitative spatial analysis can serve as a powerful complement and oversight tool for measuring impacts to transportation equity.

The purpose of this research was to provide agencies with a variety of resources and opportunities for assessing public transit equity and accessibility in their cities and regions. None of the practices have been labeled “best” because what works well in one community may work less well in another. To take one example from Section 4’s measures, although transit rider survey data are valuable for describing how people use public transit in a region, they are costly to collect and there are arguments against using revealed behavior data to understand future transit system performance. Some of the other measures summarized in Section 4 are likely to be more appropriate for agencies desiring quantitative results but without rider survey data. Staff expertise and resources may also be in short supply, pushing an agency to rely more heavily on the measures described in Section 3.

One key takeaway from this work is that transportation equity is not a box that can be checked. The agencies described in Section 3 with the most promising equity-related practices recognize that data discussions are values discussions. They imbue equity throughout the entire organization so that each decision—

whether about hiring, contracting, capital planning, budgeting, service planning, or public outreach—is undertaken with equity as one important perspective. This result suggests that agencies seeking to create more equitable public transit systems should use this report and the measures contained within it as a starting point for discussions with staff colleagues, decision-makers, and residents. Rather than seeking to identify a specific quantitative measure or equity practice to narrowly satisfy equity requirements, an agency could use multiple approaches, including quantitative and planning-oriented, to advance equity goals across multiple fronts. Surely as agencies continue to pursue equity-related goals, new policies, practices, and quantitative measures will be developed. More important than any single approach is the willingness of an agency to make equity an overarching, system-wide goal that is pursued relentlessly on multiple fronts.

Appendix A Literature Review

The existing academic literature on public transit and accessibility is vast. Rather than attempt to enumerate every study and approach, the research team identified well-cited earlier literature reviews that could be used to form a foundation upon which to expand.

Handy and Niemeier describe accessibility as “the potential for interaction, both social and economic” [15, p. 1175]. They identify three categories of accessibility measures: cumulative opportunities, gravity-based, and utility-based measures. Geurs and van Wee sought to “assess the usability of accessibility measures in evaluations of both land-use and transport changes, and related social and economic impacts” [16, p. 127]. They critically evaluated candidate measures along a range of relevant criteria, including communicability and the theoretical basis, and helpfully delineated four components of accessibility measures:

- Land use, reflecting characteristics of both origins and destinations
- Transportation, reflecting the generalized costs of travel
- Temporal constraints on individual travel, e.g., store hours or mandatory activity locations
- Individual factors, including ability, need, travel time budgets, and mode availability

Those authors note that accessibility measures employed in practice typically focus on one or more elements, but few take all four into account.

In contrast to these reviews that focused on the application or utility of various types of measures, Páez et al. [18] identified two categories of measures: normative and positive. Normative measures embed assumptions about how far people should or ought to travel, while positive measures are based on observed travel behavior. They synthesized the two approaches to calculate relative accessibility measures based on comparing positive measures to normative ones.

A final review article by Kwan [17] sought to integrate perspectives from time geography into accessibility research by shifting the focus from the properties of locations to the constraints faced by individuals. She compared and contrasted various “integral” measures of accessibility that focus on land use and transportation elements to “space-time” measures that consider both temporal constraints and individual factors. Importantly, her findings reveal that differences between demographic groups are more readily elicited using space-time rather than integral measures of accessibility.

Data Sources and Needs

Measuring or assessing accessibility or connectivity requires the use of data and different data sources lend themselves to the calculation of different measures and metrics. Historically, travel demand models have been widely used in transportation planning practice and these models have informed the calculation of accessibility measures. A travel demand model is a simulation of travel behavior typically calculated for an entire region and most often maintained by a metropolitan planning organization nominally for the purposes of complying with air quality regulation. Baseline measures of travel behavior are collected using a travel survey or activity diary, where a representative sample of regional travelers agree to participate and record their daily travel and activities over one or more days. Diary data can also be supplemented (or entirely replaced) using passively collected Global Positioning System (GPS) data, smartcard data, or other information collected using smartphone apps [166–168]. Once collected, these data are used to estimate a series of statistical models thought to result in a representation of daily travel patterns. These patterns are then combined with a representation of the transportation network to understand how the demand for travel generated by individuals and families interacts with the supply of transportation infrastructure. Often the products of interest from a travel demand model are estimates of highway congestion and public transit use. Non-motorized travel behavior is not well represented, but some agencies are making progress in this regard.

Depending on their implementation, travel demand models make certain assumptions about spatial scale and the nature of travel demand. "Four-step" models quantify travel behavior at the level of the transportation analysis zone (TAZ), a spatial unit roughly equivalent in size to a census tract [169]. Zonal demographics are split into discrete categories (e.g., income and automobile ownership) and taken through the four steps of trip generation, trip distribution, mode choice, and trip assignment. Because the trip (a one-way journey from origin to destination) is the fundamental unit of analysis, the link between traveler and travel is often obscured.

Further development of both theory and method led to the creation of "activity-based" models of travel behavior that embed the assumption that travel demand is derived from the desire for activity participation [170–172]. Activity-based models accordingly operated at the level of the individual and the household, facilitating much more fine-grained performance analyses than were possible with four-step models.

Despite the shift from TAZs to individuals, and from trips to activities, spatial (network) and temporal representations in both classes of models are similar and the outputs from both sets of models are often indistinguishable. Specifically, both groups of travel demand models generate estimates of average travel times between TAZs at specified times of day (e.g., the morning, afternoon, and evening peak periods). These estimates of congestion at specific times are key pieces of data for prioritizing and evaluating the effects of transportation infrastructure investments.

Because of the prevalence of travel demand models in practice, their representations of space and time have dominated the assessment of accessibility. Once travel times are known at the TAZ-level, measures of opportunities can be generated at the same spatial scale using many different data sources. Recent work has relied on proprietary datasets representing point locations of specific establishments as well as publicly available datasets of total jobs or jobs in different industrial or earnings categories. The US Census Bureau's Longitudinal Employer-Household Dynamics (LEHD) Origin Destination Employment Survey data has been particularly well-used [see 173].

These representations of space and time are also limiting, however, and innovations in the representation of both public transit and roadway supply have facilitated the calculation of accessibility measures that do not rely upon travel demand models. The General Transit Feed Specification (GTFS) standard has proven to be profoundly useful for spatially and temporally specific analyses of public transit service, including accessibility [e.g., 27, 28, 174, 175]. GTFS is a data standard created by Google in collaboration with Portland, Oregon's public transit agency, TriMet [176]. The goal of the GTFS standard is to provide a consistent representation of a transit agency's routes and schedules in an easy-to-share format. Since the creation of the standard, it has been adopted around the world by all manner of transit agencies. Yet not all GTFS data are created equally; low-quality GTFS data certainly exist and would be a problem from an accessibility measurement standpoint.

From an accessibility standpoint, the use of GTFS data circumvents many limitations associated with the use of travel demand model data. Specifically, representations of space and time need no longer be limited to TAZs and aggregate periods, respectively. With appropriate software and data, GTFS "feeds" provided by a transit agency can be used to calculate point-to-point travel times within a network at any minute of any day [177, 178]. The dramatic increase in spatial and temporal resolution does not come without a cost, however, as requirements related to data storage and management scale accordingly. A relational database management system (RDMS) is typically needed to store, manage, and manipulate the resultant travel time data. But such systems are widely and freely available. And the improvements in spatial and temporal resolution mean that resultant accessibility metrics are much more likely to reflect the experience of an individual traveler rather than being a property of space. An added benefit is that travel demand models—and the associated runtimes—need no longer be relied upon for data provision. Most work to date using GTFS feeds to understand public transit levels of service has focused on walk-to-transit access modes by integrating GTFS data with a representation of the pedestrian network. Park-and-ride access could also be modeled in principle but would require the creation of an additional network that integrates roadways (assuming automobile travel speeds) and GTFS feeds.

Proprietary software packages are available that facilitate the calculation of travel times using GTFS data. These include the "Add GTFS to a Network Dataset" created by ESRI, Conveyal's Analysis, and Remix, among others. Open-source solutions are also being offered, including UrbanAccess (https://github.com/UDST/urbanaccess),[14] and bespoke tools created to address specific research questions [e.g., 29]. The FTA's freely available, but not open-source, Simplified Trips-on-Project Software (STOPS) includes GTFPath, a utility that takes a GTFS feed and zonal centroids as input and outputs zone-to-zone travel times.

Travel times calculated using existing GTFS feeds are helpful for assessing the performance of an existing network, but to assess the impacts of potential changes, the underlying GTFS feed must be altered, and the analysis run again. Software is also available that facilitates the creation and maintenance of GTFS feeds, including GTFS Manager (created by Trillium Solutions, Inc.), Conveyal's Transit Data Tools suite, and GTFSEd (whose creation was sponsored by FTA). Finding software that is still being maintained and updated can sometimes be a challenge.

Almost without exception, the existing literature relies upon the static GTFS feed representing the ideal, or expected, public transit schedule. In practice, however, actually delivered transit service is likely to differ, sometimes substantially, from that expected based on the schedule [e.g., 32]. Google developed an additional data standard known as GTFS Realtime to provide information about these types of day-to-day variations in public transit schedules. GTFS Realtime is designed to be consumed by an app or a web application to give a user current information about a transit system or a particular trip. But the Realtime data can be stored and archived to facilitate later analysis of system performance [31]. Realtime data are not as well used as the static GTFS feeds, likely because of the relatively greater demands working with Realtime feeds places on data acquisition and management.

Clearly, there are many different data sources for assessing public transit accessibility and connectivity. If the underlying data differ, results might

[14] GitHub is a website that facilitates the storing and sharing of software. Discrete projects are associated with individual "repositories" that can be updated over time as the underlying code is refined. GitHub users can follow specific projects and improve the underlying code by making changes to their local version and sending a request to the individual or team responsible for maintaining the project to which they're interested in contributing.

not be the same even when similar measures are used. Care is therefore needed to ensure the results generated by a specific accessibility analysis are understandable and expected on the part of a transit agency or the public.

Measures and Metrics

Access to Infrastructure/Access to Transit

The most basic type of accessibility measure relevant to public transit systems considers only access to the system itself. In other words, transit alone (e.g., routes, stops, or stations) is seen as the end, rather than as the means to reach desired destinations. Measures that address access to infrastructure or access to transit attempt to capture key variables related to transit service including, among others, distance to the nearest station or stop, the number of nearby stations or stops, or frequency of nearby service. Sometimes these indicators are combined into a composite index. Like other measures, they can be calculated at different geographic scales.

Wu and Hine [179] defined "public transport accessibility levels" based on expected walking and waiting time to nearby transit stops without including metrics of the number of opportunities that could be reached by public transit. Al Mamun and Lownes [180] combined three indicators calculated at the census tract level to create a composite index of access to transit services. The three components included a "local index of transit availability" that considered transit vehicle capacities, the proportion of a tract covered by a route, and vehicle capacities among other factors; a measure of service coverage derived from the Transit Capacity and Quality of Service Manual; and a final measure that takes into account the time-of-day distribution of overall travel demand. Currie [121] and Delbosc and Currie [181] both analyzed the relationship between areas designated as socially disadvantaged and measures of public transit supply based on distance to transit stop and vehicle frequency. Frappier et al. [123] examined the number of alternative transit options available to make a trip between origin and destination, as well as various measures of service quality including travel time, rather than the characteristics of the destination per se.

Access to Opportunities

A broad category of accessibility indicators can be referred to as access to opportunities indicators. The standard mathematical formulation of such indicators is shown in equation A1:

$$\boldsymbol{A_i = \sum_j O_j f(C_{ij})} \qquad \text{(A1)}$$

where:

A_i = accessibility for location *i*,

O_j = “opportunities” at location *j* (e.g., number of jobs, square feet of retail space, number of grocery stores),

C_{ij} = travel cost between *i* and *j*, and

F(□) = impedance function.

Different forms of the impedance function imply different types of accessibility. Two of the most common forms of the function result in “cumulative opportunities” and “gravity” measures of accessibility. These functional forms are summarized in equations A2 and A3.

$$f(C_{ij}) = \begin{cases} 1 \text{ if } C_{ij} \leq t \\ 0 \text{ if } C_{ij} > t \end{cases} \quad \text{(A2)}$$

$$f(C_{ij}) = e^{-\beta Cij} \quad \text{(A3)}$$

where:

t = travel time threshold, and

β = empirically derived impedance term.

The cumulative opportunities formulation of accessibility (equation A2) has seen widespread application. It is often argued to be the most interpretable and transparent accessibility measure because it is relatively straightforward to calculate and facilitates comparisons across places once the total number of opportunities are normalized [125–127, 182]. That the measure is readily interpretable is difficult to dispute. An example illustration is shown in Figure A-1 for the metropolitan statistical area centered on Chicago, IL. The figure is taken from a much larger, ongoing study entitled *Access Across America* [127, e.g., 183].

Figure A-1 shows the number of jobs that can be reached within an average 30-minute public transit trip during the morning peak period from all origin locations within the region. It demonstrates that accessibility is highest in the urban core and proximate to high-frequency transit lines. Travel costs, times, and distances can be measured for different modes and at different times of day, so different metrics can be calculated for the same location. They can also be compared to examine the accessibility benefits provided by relatively faster modes. The measure is limited in that it does not differentiate between opportunities located just before and just beyond the threshold. Setting a discrete threshold effectively embodies assumptions about what types of public transit trips are “reasonable” to make.

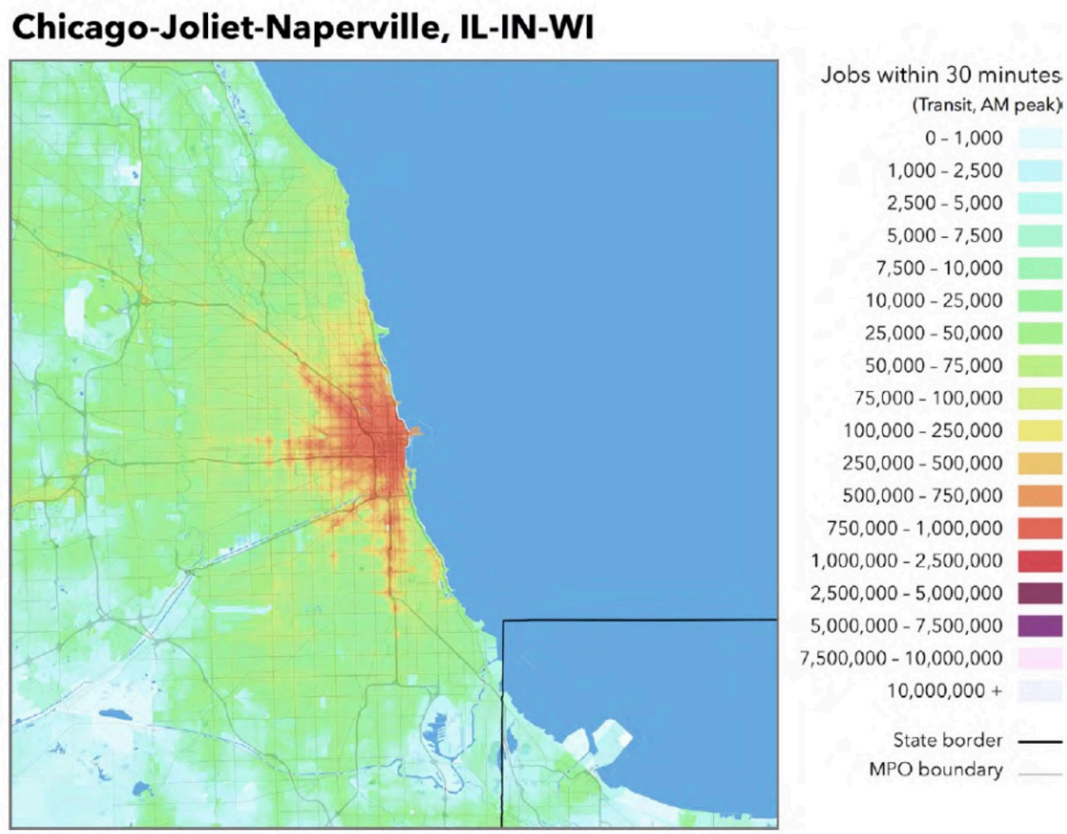


Figure A-1 *Illustration of cumulative opportunities accessibility to total jobs in the Chicago-Joliet-Naperville metropolitan statistical area*

Source: Owen et al. [183, p. 26]

The gravity formulation of accessibility (equation A3) relaxes some of the limitations inherent in the cumulative opportunities formulation. Specifically, it considers all opportunities within a given area regardless of the travel time it takes to reach them. Instead, it "weights" opportunities located closer to the origin more heavily. In this way, it does not require restrictive assumptions about the appropriate threshold to use when calculating a cumulative opportunities measure. On the other hand, the accessibility measure so calculated cannot be directly interpreted as the count of total opportunities. Instead, it is a dimensionless value that only has meaning within the context of a single region. Figure A-2 shows an accessibility map created using a gravity measure calculated for the three counties surrounding the city of Detroit, Michigan (Wayne, Macomb, and Oakland counties).

Calculating a gravity measure requires the analyst to specify the impedance term by direct estimation using observed travel behavior taken from a regional travel survey to create an empirical trip-length frequency distribution onto which an exponential distribution can be fitted. The "rate parameter" of the exponential distribution becomes the impedance term. Larger (smaller) values of the impedance indicate that trips are generally shorter (longer); the friction of space is high. Because of the spatial distribution of destinations and the relative importance of different trip types, the parameter is known to vary by trip purpose and region [184]. The impedance parameter can also be applied from another region or another modeling application if regional travel data are unavailable.

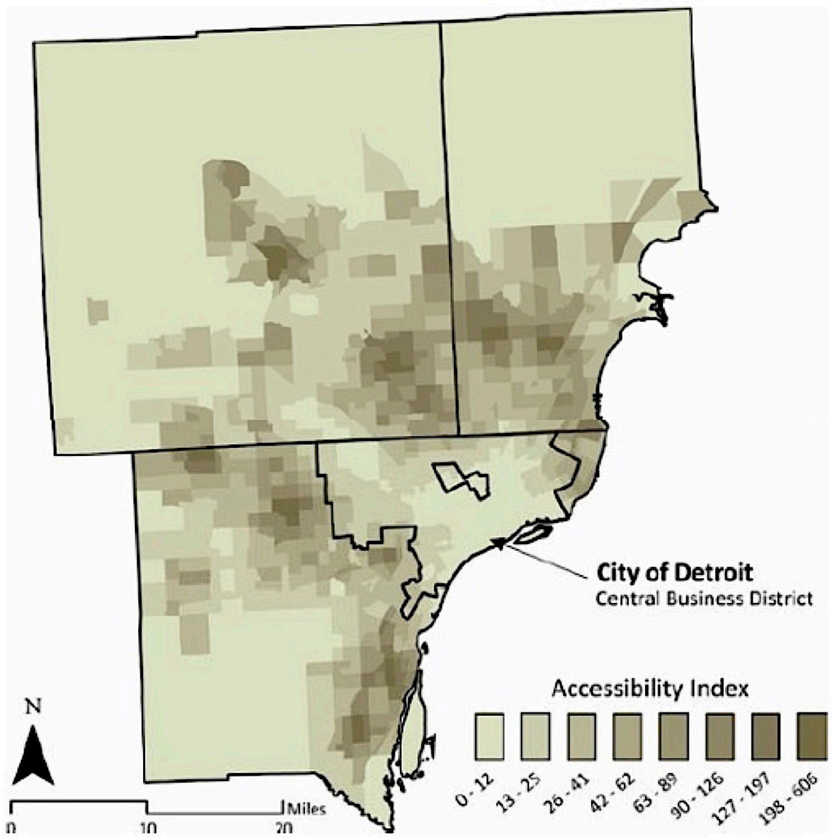


Figure A-2 *Gravity-type accessibility to convenience stores by automobile in the three-county Detroit region*
Source: Grengs [184, Figure 3]

A final category of access to opportunities accounts for competition to certain types of destinations, namely employment. These "competitive" accessibility measures consider not only access to a single origin to possible destinations, but rather discount the apparent accessibility of the origin by considering all those located elsewhere in the region who can also access that location. These measures were initially developed by Shen [132, 133] and were subsequently applied more widely [130, 131, e.g., 185, 186].

The most complete formulation of this accessibility measure accounts for the relative population shares with access to an automobile as compared to those dependent on transit. These are summarized in equations A4 and A5:

$$A_i^{auto} = \sum_j \frac{O_j f(C_{ij}^{auto})}{\sum_k [\alpha_k P_k f(C_{kj}^{auto}) + (1-\alpha_k) P_k f(C_{kj}^{tran})]} \qquad (A4)$$

$$A_i^{tran} = \sum_j \frac{O_j f(C_{ij}^{tran})}{\sum_k [\alpha_k P_k f(C_{kj}^{auto}) + (1-\alpha_k) P_k f(C_{kj}^{tran})]} \qquad (A5)$$

where all parameters are defined as previously and:

P_k = population in location *k*, and

α_k = proportion of population in location *k* with access to an automobile.

In short, the competitive measures discount the apparent accessibility of a location to jobs by considering all other individuals who can reach those same jobs. All else equal, locations will score more highly on the competitive accessibility measure if there are fewer similarly skilled workers competing for the same jobs and located close by. Visually, the appearance of competitive measures is not much different from cumulative opportunity or gravity-type measures. An example is shown in Figure A-3, with measures calculated for metropolitan Milwaukee, WI, and for commuters using both automobile and public transit. The figure shows that the areas of highest accessibility by automobile are not concentrated in the vicinity of downtown but are somewhat more dispersed. This spatial variation reflects the relative locations of employment demand and supply.

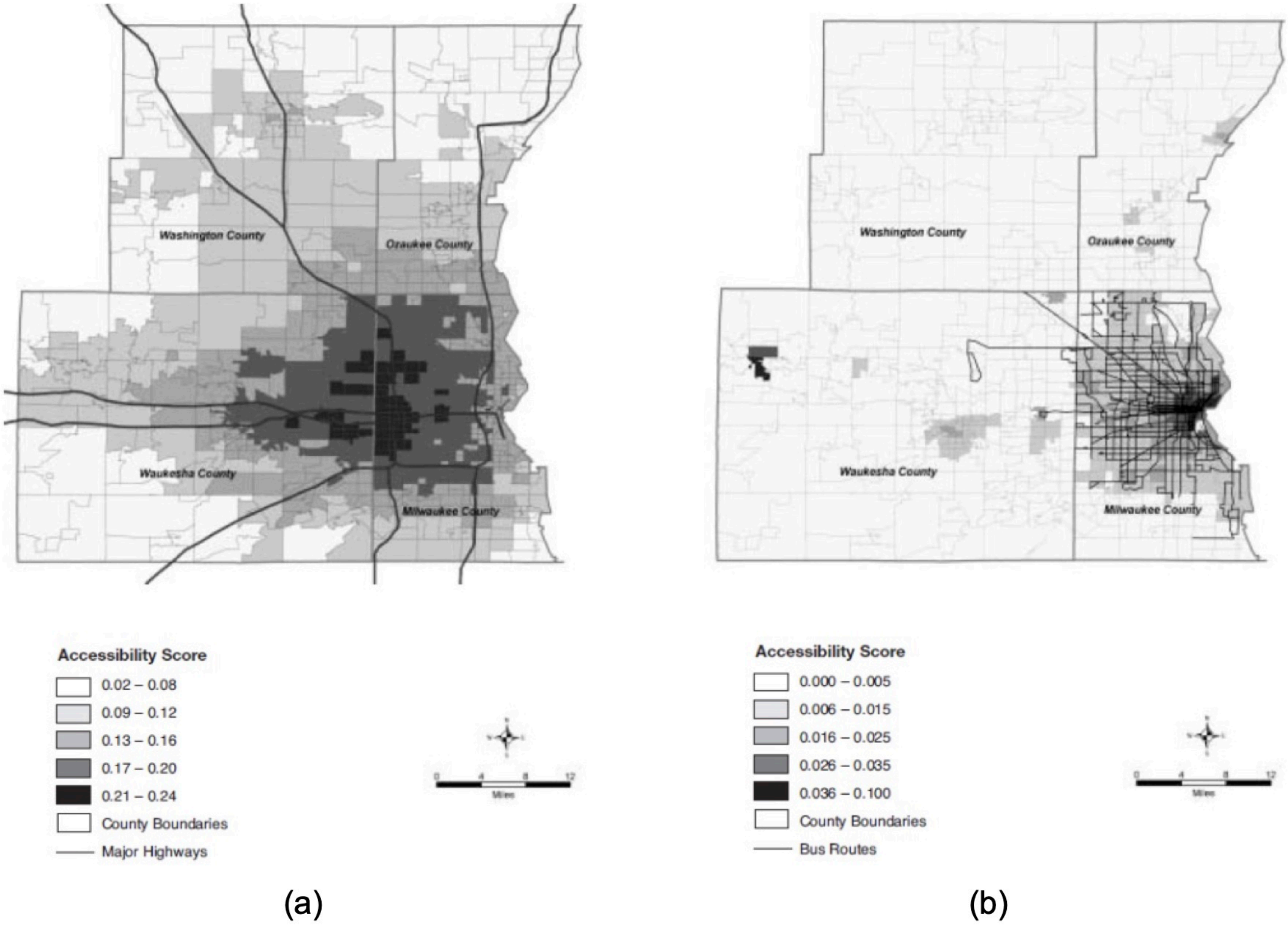


Figure A-3 *Gravity-type accessibility to convenience stores by automobile in the three-county Detroit region*

Note: Thresholds used to categorize each group of accessibility measures are not equivalent across modes; all five categories visualized for transit fit almost completely within the first two categories for automobile.

Source: Shen and Sanchez [187]

Regardless of the form of the access to opportunities indicator, side-by-side comparisons similar to those summarized in Figure A-3 can be helpful for eliciting the differences in access to opportunities using automobile and public transit, and often demonstrate the vast differences between the accessibility afforded by the two modes [126, 132, 133, 188, 189]. The greatest value of the accessibility index visualized in Figure A-3(b) is 0.1, meaning that almost all the five categories shown for public transit fit within the first two categories visualized for automobile in Figure A-3(a). This result demonstrates the automobile's vast superiority over public transit and highlights the importance of comparative assessments.

Modeled Accessibility

The denominator of a multinomial logit mode choice model can also be interpreted as a measure of accessibility. Following Niemeier [144], the "logsum" can be defined as shown in equation A6:

$$A_n = \ln\left(\sum_{\forall k \in TC} e^{V_{nk}}\right) \tag{A6}$$

where:

A_n = accessibility for individual *n*,

V_{nk} = deterministic portion of the utility of choice *k* for individual *n*.

The overall utility of a transportation choice is known to depend on characteristics of the individual (e.g., socioeconomic status, race, gender, household size, automobile ownership, attitudes about travel) and mode (e.g., travel time, monetary cost, relative comfort) [190]. In general, larger choice sets with higher utility alternatives result in higher accessibilities using this measure.

The challenge of modeled accessibility indicators lies in their interpretability and the inability to compare across different model formulations. A full multinomial logit model must be estimated using revealed choices to identify the effect of each independent variable on overall utility. Different model structures might result in different marginal values of any independent variables. Additionally, utility has no absolute meaning on its own; it is only meaningful when viewed comparatively. Logsum measures have therefore been applied most frequently when comparing outcomes for individuals under different transportation scenarios.

Other "Connectivity" Measures

Because they are composed of nodes (stops and stations) and links (routes and lines), transit networks can be represented by mathematical graphs. These types of representations are ubiquitous, appearing in studies of social networks, the internet, electrical distribution systems, disease transmission, biological systems, international trade, and several other areas. Performance metrics can be readily calculated to describe the entire network or portions of it. Such performance measures have existed for some time [see 191, 192], but have only recently begun to be applied to the analysis of public transit systems.

The delay in application likely arises from the relative complexity of public transit systems. Whereas a single link always connects two nodes in a highway network, a public transit system might have different routes serving particular pairs of nodes [193, 194]. Further, in order to be meaningful, connectivity performance measures for public transit would have to consider underlying properties of the transit system including vehicle capacity and ridership, fares, headways, operating hours, the nature and quality of destinations reachable from particular network locations, the number of required transfers, the quality of the pedestrian environment, as well as any other factors of interest to members of the public or the analyst.

One measure of network connectivity that has seen widespread application in the literature is the degree of centrality. The centrality of a node is calculated as the number of other nodes that are directly connected to it, typically normalized by the total number of nodes in the network. Clearly, this measure has little utility if used directly without modification. Because travel is a derived demand, the quality and quantity of reachable destinations (activity opportunities) also has to be taken into account. In recent literature, a number of authors have demonstrated how such traditional connectivity metrics can be extended and applied to public transit systems [193–196]. Specifically, Mishra and colleagues have developed indicators of node connectivity that are calculated using average values of frequency, capacity, proximity to other nodes, and nearby activity density (jobs and households per unit area).

Revealed Behavior and "Individual" Accessibility

In contrast to the abundant literature on generic access to opportunities, there is comparatively less work that uses revealed travel behavior to assess baseline accessibility or how accessibility will change under alternative scenarios. The form that revealed behavior takes in the analysis can vary substantially. Perspectives from time geography encourage the incorporation of travel behavior and related constraints to inform the creation of new types of "individual" accessibility measures, while more traditional access to opportunities measures can also be modified to incorporate travel patterns [17, 18]. On the other hand, changes in travel time also partly reflect changes in accessibility, and measures such as travel time savings and congestion reduction have been widely used in performance assessments in practice [e.g., 26]. One limitation of travel time savings is that they do not measure the quantity of opportunities available so their consistency with true accessibility measures is debatable.

Shifting to a revealed behavior perspective is not an all-or-nothing proposition. Work conducted by Antonio Páez and colleagues has demonstrated multiple ways that revealed behavior could be incorporated into accessibility analyses. Páez et al. [140] developed "relative accessibility deprivation indicators" to assess disparities in access to food in Montreal, Quebec, Canada. A key innovation of their work was the estimation of linear models of distance traveled that considered an individual's residential location and demographic characteristics based on travel survey data collected for the Greater Montreal Area. The resultant "spatially expanded" linear regression could be used to set the threshold for a cumulative opportunities accessibility measure that varied across space and individuals, as opposed to the typical approach where the threshold is fixed across an entire area. Importantly, they also defined equity-relevant measures, assessing the relative proportions of total opportunities reachable by an individual from a particular location in the region based on household income. They later applied similar measures to examine accessibility to health care facilities by senior and non-senior residents of Montreal [197].

While this prior work incorporates measures of revealed behavior, it focuses only on distance traveled and thus only indirectly engages with differences between modes. Other research has focused on public transit directly. Farber et al. [198], for example, sought to move beyond the use of zonal demographics to identify the demand for public transit, instead using the results of an origin-destination survey for this purpose. Those authors noted that "Transit need is poorly characterized by zonal population characteristics since different population groups demand travel to different types of destinations at different times of the day" (p. 41). The general absence of revealed travel measures in the literature can be partially explained by the relative ease of using population shares as a proxy. Using travel survey data often requires the completion of data use agreements and statistical software to facilitate the analysis of complex survey samples. In contrast, Farber et al. examined *actual* demand based on a regional household travel survey combined with an onboard transit survey.

Prior to the introduction of GTFS data, a number of accessibility studies were conducted that relied on different sources of data to complete their analyses. For example, Polzin et al. [199] incorporated more explicit temporal measures of public transit accessibility, considering the span of service, time-of-day distribution of (total) travel demand, and maximum permissible wait times. Their analysis differed from others in that key indicators were calculated at the level of a transit route; routes are assumed to serve some portion of the population residing in zones that they cross. These variables were combined to derive a final measure of "Daily trips per capita for which transit service is available." The measure so calculated is not a true accessibility measure, however, since it only considers the match between time-of-day, transit service, and trip generation. There is no explicit link to destinations or opportunities. The indicator can instead be interpreted to reflect the consistency between transit trip frequency and trip generation rates, without considering the destination. In other words, what share of trips are "exposed" to transit service? Further, the method was developed pre-GTFS, so transit route and schedule information had to be manually coded.

Also working pre-GTFS, Lei and Church [19] developed and evaluated a number of transit accessibility figures based on round-trip travel times between origins and destinations, including multiple specific destinations. They also proposed a method for evaluating the impact of service changes on accessibility, identifying measures of "cumulative change" that evaluate changes in OD travel times for all possible OD pairs under a modified service plan with and without considering the actual demand for travel along each pair.

The travel time savings associated with proposed changes in public transit service can also be evaluated. Manaugh and El-Geneidy [151] combined analyses of changes in access to opportunities measures and travel times expected to result from the implementation of the Montreal Transportation Plan. Their work included existing origin-destination locations for work trips (regardless of mode) gleaned from Statistics Canada sources.[15] They calculated three sets of measures, including:

1) Changes in cumulative opportunities access to jobs requiring a high school education or less, considering origin areas of high social disadvantage.

2) Change in travel time to six pre-identified employment centers from the same areas of high social disadvantage.

3) "Potential" travel time savings considering actual locations of home and work (but not considering patterns of public transit use).

Their definition of socially disadvantaged considered multiple demographic and population characteristics, including public transit commute mode share. Their results highlight a number of methodological issues related to appropriate scale and the implications of aggregation. In particular, they demonstrated that using measures such as access to total jobs can mask variation that only becomes evident when examining access to jobs that are skills-matched to the populations of interest. They also highlighted differences between access to opportunities (potentially longer term) and travel time measures (more immediate). In general, the plan they analyzed seemed to provide substantial benefits to the socially disadvantaged areas.

Importantly, neither of these studies considered savings that would accrue to the population using public transit, except for indirectly in the case of Manaugh and El-Geneidy [151] using transit mode share in their disadvantaged community definitions. Additionally, no demand forecasting was undertaken to determine whether, for example, service changes would draw new users into the system.

Opportunity vs. Revealed-Behavior Measures

A focus on revealed travel behavior has been criticized in the literature on at least two fronts [9, p. 177]. The first is based on the argument that observed travel patterns reflect some combination of both individual preferences/choices and constraints and that teasing out which is the dominant force in any situation

[15] Statistics Canada has responsibilities roughly equivalent to the US Census Bureau. They conduct censuses every five years and maintain a number of different ongoing surveys.

is difficult. For example, an observed long commute may reflect a low-wage worker's inability to find housing close to their job or a high-wage worker's preference for high housing consumption and the high-quality schools in a suburban area. While both situations are potentially problematic from a policy standpoint, their remedies differ. Providing affordable housing close to low-wage jobs could shorten low-wage commutes in general, while in the latter case, increasing the cost of driving would be likely to encourage shifts in residential location choices. Any assessment of observed travel patterns that does not account for this distinction will probably be comparing apples to oranges.

Surprisingly little work has been completed related to differences in travel behavior and satisfaction with travel between groups that appear similar on basic variables such as automobile ownership. But there is an emerging literature that compares households that choose to not have an automobile ("voluntary" or "low-car" households) to those that would like to have one but cannot afford it or who have access to fewer vehicles than licensed drivers ("involuntary" or "no-car" households). In a study of the differences between these two groups in Australia using original survey data, Delbosc and Currie [200] reported that low-car households tended to be in areas where non-automobile alternatives were much more readily available. No-car households, on the other hand, tended to drive more and have more restrictions on activity participation. Using, the 2012 California Household Travel Survey, Brown [155] examined demographic and trip-making differences between the two groups. Because of the representative nature of the statewide survey, she was also able to identify the overall share of each group, finding that involuntary zero-vehicle households composed the lion's share of all zero-vehicle households in the state, at 79%. They also tended to make fewer trips and travel fewer miles per day. Similar approaches could be used to split a regional population into separate and relatively consistent groups.

The second, and related, criticism of revealed behavior measures concern suppressed trips; individuals and families may have travel demands that are not being met because of their circumstances (residential locations, incomes, vehicle holdings) and those related to the transportation system (public transit routes and schedules, availability of highway infrastructure). By definition, these trips will not be visible in datasets of revealed travel behavior. A series of studies on how transportation disadvantaged populations fulfil their mobility needs revealed that vehicle ownership and availability can sometimes be ephemeral in certain populations and that getting rides through social networks was frequent [156, 201]. Later research has confirmed that automobile ownership is not a static variable for many families [202]. Nordbakke and Schwanen [157] examined older adults in Norway and found that the availability of public and private transportation options increased their ability to participate in out-of-home activities.

Thus, one challenge of using measures of revealed behavior is that any analyses will ignore certain types of mobility-restricted individuals. An analysis of the travel time savings expected to result from an infrastructure improvement based on existing system users, for example, would only reflect impacts on those users. Those currently opting out of the system will be excluded. These two related factors—the inability to differentiate between travel behavior undertaken by choice/prohibited by constraint and the absence of revealed behavior for disadvantaged populations—has led some researchers to advocate against using revealed preferences in accessibility or equity assessments [9]. Instead, they prioritize the use of pure opportunity measures because (it is argued) such measures give some sense of the potential for opportunity engagement and activity participation while eliding questions related to choice, constraint, and suppressed trips. Others have argued for a more relative approach that combines measures of opportunity accessibility with observed mobility patterns [203]. Appropriate policy and planning responses are likely to vary in areas with high or low access to opportunities when responding to populations with low mobility patterns.

Equity Assessments

Both academic and practitioner interest in transportation equity has been fueled by work revealing that key measures of travel behavior (e.g., mode choice, automobile ownership) vary systematically with individual- and household-level characteristics [e.g., 154, 189, 204, 205] and that historical patterns of discrimination in the provision of public services have been widespread [e.g., 206]. The rise of geographic information system technology and publicly available data on transportation has made the assessment of transportation equity easier than ever. Transportation equity is undergirded by federal requirements to conduct meaningful public engagement and to ensure a fair distribution of the benefits and burdens of transportation investments [39, 207]. Questions of equity and fairness emerge separate and apart from how access to opportunities is quantified.

Regional transportation planning agencies, guided in part by Title VI of the 1964 Civil Rights Act and President Clinton's 1994 Executive Order on environmental justice, too, have completed equity analyses of their regional transportation plans [208]. But there are few standards to follow, and agencies rarely find evidence of inequity [5, 6, 11, 37, 209]. Some of the most well-developed equity-related guidance has emerged from the Federal Transit Administration and its circulars on Title VI and environmental justice compliance among its fund recipients [210, 211]. FTA's guidance emphasizes the comparison of demographic shares affected by a proposed service or fare change as its key measure of disproportionality [4]. While these measures may be important from a civil rights perspective, they do not reflect important elements of access to opportunities [30].

In parallel with regulatory and legal requirements, a growing cottage industry in transport geography has been assessing the relationship between transportation supply and demand in regions across the United States and around the world [27, e.g., 121, 175, 197, 198, 212, 213]. Transit demand is generated by individuals and demographic groups with a need or desire to forego the use of a private automobile and is usually quantified using the census demographics of zones (e.g., standardized proportions of low-income and people of color populations). A primary interest of this body of work is to determine whether locations of high transit demand experience low supply. In other words, is there a "needs gap" that exists between these two locations.

A necessarily abridged summary of needs-gap studies appears in Table A-1. A key distinction in this literature has previously gone unnoticed. This distinction arises from the framing of the analysis, referred to as the "study type" in Table A-1. Prior work seeks either to (1) assess the aggregate performance of a metropolitan region, arguing that given a set of historical or existing conditions, equity is or is not a concern (referred to here as "regional assessment") or (2) identify particular locations with high demand and low supply (referred to here as "identification").

Because of the historical location of people of color and low-income people within central cities in the United States and the concentration of transit service there, work that examines transit supply and demand in the aggregate often indicates that there are no disparities: locations with the highest concentrations of disadvantaged populations also have the highest concentrations of transit service. But the analysis is not often sensitive to the actual travel needs of these populations. For example, if a supply metric is frequency or distance based, the match between high frequency and high demographic needs reveals little about whether transit reaches desired destinations at convenient times. Even the use of true accessibility measures may not circumvent this shortcoming, as they could examine a single point in time or irrelevant types of opportunities.

On the other hand, identification-type studies typically highlight areas that are difficult to effectively serve with public transit or those where there is a relatively high concentration of identified transit users. But because these studies rely upon relative measures of supply and demand, identifying mismatches is a near-inevitability—there will always be locations where supply is relatively low and demand is relatively high. This result provides little information about whether transit service is sufficient to meet daily needs or how performance varies for those who rely on transit versus those who have access to an automobile [but see, 126].

For example, Jiao [214] identified locations near the University of Texas at Austin as evidencing a supply/demand imbalance, even though those locations are well-served by public transit. The problem is methodological—those are also locations with high numbers of students who do not own automobiles. Even though they might be served with sufficient transit service, because their population numbers are so large, the standardized total overwhelms that of the transit supply, resulting in an imbalance. Pegging absolute values of transit service to specific z-scores (e.g., those above the 75th percentile) and determining where high-demand locations fall short of that supply standard may be a more promising analytical approach. Incorporating more precise estimates of transit use, and the effects of service changes on travel behavior, would add another helpful dimension to the analysis. There is surprisingly little work that examines this relationship in an equity context, but the "sketch planning" literature has examined the relationship between the demographics of service areas and Euclidian buffers around transit stops and stations and daily boardings [e.g., 215–217].

Two additional limitations are clear from the literature summarized in Table A-1. First, demand metrics often mix several different demographic groups whose travel needs are unlikely to overlap meaningfully [35]. Additionally, merging demographic groups in this manner ensures that the final zones identified as having high "demand" will be unlikely to represent conditions faced by any particular group [6, 136]. This merging is particularly relevant from a civil rights compliance perspective, since the analysis must represent conditions for particular racial and ethnic groups compared to a reference group. Locations of high demand could contain low concentrations of people of color if concentrations of other demographic groups were high. Any "gap" calculated would then be irrelevant from a civil rights compliance perspective.

The second limitation concerns the near absence of actual travel behavior. In discussing needs-gap studies, Farber et al. note that "Transit need is poorly characterized by zonal population characteristics since different population groups demand travel to different types of destinations at different times of the day" [198, p. 41]. Those authors conduct one of the only needs-gap studies that examines actual demand based on a regional household travel survey combined with an onboard transit survey. The general absence of actual travel patterns can be partially explained by the relative ease of using demographics and population shares as a proxy. Using travel survey data often requires the completion of data use agreements and statistical software to facilitate the analysis of complex survey samples.

But if only potential measures such as access and accessibility are examined, a system may appear equitable even if observed travel patterns result in vast disparities between commute times, travel distances, or transportation cost burdens between racial and ethnic groups. If an equity analysis based on revealed behavior indicates disparities, then employment and residential discrimination, economic development, and affordable housing policies are all implicated.

Table A-1 *Needs-Gap-Type Studies on Public Transportation Provision and Demand*

Reference	Location	Mode	Supply Metric	Demand Metric	Study Type	Key Findings
Blumenberg and Ong [188]	Los Angeles, CA, USA	Transit	Accessibility to low-wage, feminized occupations by TAZ (cumulative opportunities)	Residential location of welfare recipients	Identification	Public transit is likely to work well for those welfare recipients living in job rich neighborhoods but not well for those in job poor areas; these workers would benefit more from automobile ownership.
Murray and Davis [218]	Southeast Queensland, Australia	Transit	Proportion of population with transit stop or station within 400m	Young, ages, low-income, zero-vehicle households, disabled	Identification	Many suburban areas demonstrated high transit need based on discrete thresholds applied to supply and demand metrics.
Wu and Hine [179]	Belfast, Ireland	Transit	Access indicator considering distance to stop and expected frequency	Income, employment, health/ disability, education, service proximity, social environment, housing	Regional assessment	Results demonstrate the average change in access levels across the region under different service change scenarios.
Currie [219]	Hobart, Tasmania, Australia	Transit	Generalized cost of travel by trip purpose	Automobile ownership, distance to CBD, elderly, disabled, low-income, unemployed, students	Identification	Urban fringe areas contain a high degree of public transit need and generally poor service.
Currie [121]	Melbourne, Australia	Transit	Combined indicator of service frequency and access distance	Same as Currie (2004)	Identification	Identified urban fringe areas with a high degree of public transit need and generally poor service.

Table A-1 (cont.) *Needs-Gap-Type Studies on Public Transportation Provision and Demand*

Reference	Location	Mode	Supply Metric	Demand Metric	Study Type	Key Findings
Al Mamun and Lownes [180]	Meriden, CT, USA	Transit	Composite index based on three methods including coverage, frequency, and capacity of service	Proportion of transportation disadvantaged populations including: forced car ownership households (low-income and high auto ownership), zero vehicle households, low-income people, older adults, and people with disabilities (disabled)	Identification	Use of disadvantage plus automobile dependence was novel. Proposed a combined indicator of service and need. Demonstrated how it could be applied to improve accessibility for an individual tract.
Delbosc and Currie [181]	Melbourne, Australia	Transit	Composite measure of service frequency and access distance to stop or station	Total population and employment (horizontal equity) and age, income, and automobile ownership (vertical equity); vertical equity indicators stratified for three geographic regions (inner, middle, outer)	Identification and regional assessment	Horizontal equity was low—small portions of the population enjoyed the majority of access to transit. Vertical equity showed preference for different groups in different locations. Zero-vehicle households tended to be located in areas with good transit service.
Jaramillo, Lizárraga, and Grindlay [220]	Santiago de Cali, Colombia	Transit	"Index of public transport provision" including public transit frequency, capacity, number of stops	"Index of transport social needs" including > 15 person (e.g., vehicle ownership, age, employment status) and place (e.g., service density) factors	Identification	Gaps calculated as the difference between need and provision. Fringe areas far from the city center showed the largest gaps between need and provision, reflecting prevailing urban forms and settlement patterns common in Latin American cities.

Table A-1 (cont.) *Needs-Gap-Type Studies on Public Transportation Provision and Demand*

Reference	Location	Mode	Supply Metric	Demand Metric	Study Type	Key Findings
Tribby and Zandbergen [221]	Albuquerque, NM	Transit	Travel time savings for hypothetical trips to downtown	Low-income, zero-vehicle households, seniors (aged 65 and greater), and the young (aged 19 or younger)	Regional assessment	Investigated the impact of new bus rapid transit service. Identified a negative correlation between transit "need" and potential travel time savings.
Foth, Manaugh, and El-Geneidy [222]	Greater Toronto, ON, Canada	Transit	Gravity-type accessibility to all jobs, low skill jobs, and all other jobs (not low skill); average travel time by transit based on actual commute OD pairs	Income, unemployment, recent immigrants, housing cost burden	Regional assessment	Examined needs gaps at two points in time: 1996-2006 to assess change. The most "socially disadvantaged" tracts have the greatest transit accessibility and shortest travel times. Their conditions improve over the analysis period despite some evidence of the suburbanization of disadvantage.
Hart and Lownes [212]	New Haven, CT, USA	Transit	Accessibility to low-wage jobs (cumulative opportunities)	Low-income households with high rates of automobile ownership	Regional assessment	Sought to determine whether transit accessibility was associated with lower vehicle holdings among low-income households. Late-night service frequency and transit accessibility showed a weak relationship to low-income job accessibility.

Table A-1 (cont.) *Needs-Gap-Type Studies on Public Transportation Provision and Demand*

Reference	Location	Mode	Supply Metric	Demand Metric	Study Type	Key Findings
Golub and Martens [126]	San Francisco Bay Area, CA, USA	Automobile and transit	Accessibility to job categories by transit and automobile, and their ratio	Low-income and minority populations	Identification and regional assessment	Study defined an "accessibility poverty" indicator to identify areas with poor transit relative to automobile accessibility and compared outcomes across several regional transportation planning scenarios. Project scenarios generally reduced levels of access poverty across demographic groups.
Fransen et al. [175]	Flanders, Belgium	Transit	Composite pseudo-gravity-based cumulative opportunities accessibility to six types of non-work destinations as well as total jobs	Factor analysis of age, zero vehicle households, unemployment, welfare recipients, and proximity to primary services	Identification	Uses contemporary GIS methods to calculate travel times by transit between TAZ pairs at two time periods. Identifies areas with high need. Assessment of different time periods did not substantially change results. Consideration of temporal variability in transit service did not change much.

Table A-1 (cont.) *Needs-Gap-Type Studies on Public Transportation Provision and Demand*

Reference	Location	Mode	Supply Metric	Demand Metric	Study Type	Key Findings
Grengs [184]	Detroit, MI, USA	Automobile and transit	Gravity-based accessibility to 13 types of non-work destinations; estimation of the impedance parameter using an OD survey; zonal accessibility was a weighted mean of automobile and transit based on levels of vehicle ownership	Race, income, poverty status	Regional assessment	Goal was to assess overall regional accessibility to key non-work destinations. Cumulative proportions of households were plotted against accessibility. Found that the Black population in general had higher accessibility (relative to non-Hispanic Whites) to convenience stores and banks, while the non-Hispanic White population had higher accessibility to supermarkets and shopping.
El-Geneidy et al. [223]	Greater Toronto-Hamilton Area, ON, Canada	Transit	Gravity-type accessibility (regular and a competitive measure) to low-wage jobs, and all other jobs (not low-wage); average travel time by transit based on actual commute OD pairs	Income, unemployment rate, recent immigrants, housing cost burden	Regional assessment	Methods very similar to Foth et al. (2013). Differences apparent between regular gravity accessibility and competitive accessibility metrics. In general, high social disadvantage is associated with higher transit accessibility and lower commute times.
Farber et al. [198]	Salt Lake City, UT, USA	Transit	Temporally precise estimates of travel time by transit matched to an OD survey	All measures included on the od survey were investigated	Regional assessment	One of the only studies to associate actual travel behavior (demand) with observed supply (travel time). Results showed that some measures of disadvantage were associated with poorer transit service provision in terms of higher travel times.

Table A-1 (cont.) *Needs-Gap-Type Studies on Public Transportation Provision and Demand*

Reference	Location	Mode	Supply Metric	Demand Metric	Study Type	Key Findings
Jiao [214]	Austin, Dallas, Houston, Fort Worth, San Antonio, TX	Transit	Various supply-based criteria including number of transit stops and length of sidewalk at the block group level	"Transit dependents" – identified using vehicle availability	Identification	Used a difference of z-scores to identify locations with high apparent transit demand and low supply

Practice Review

Many tools and products exist to analyze public transit ridership and accessibility in the context of analyses relevant from a public transit planning perspective. The incorporation of the most advanced findings from geographic information science and applied geography are rare, but more standard measures of accessibility and some measures of revealed behavior have appeared in practice.

Simplified Trips-on-Project Software

Simplified Trips-on-Project Software (STOPS) is a suite of tools developed by FTA pursuant to a 2013 rulemaking that changed the way Capital Investment Grant Program projects are evaluated.[16] STOPS provides project sponsors with a simplified alternative to the regional travel demand forecasting models that would otherwise be used to quantify some of the project performance measures specified by the final rule. The two performance measures that can be calculated by STOPS are mobility benefits represented by projected ridership and environmental benefits represented by automobile VMT (vehicle miles traveled) reduction [224].

STOPS version 2.01 has three different operating modes. Each embodies different data requirements, so their use depends upon the detail and extent of existing transit trip data in a location. The simplest of these is the synthetic mode, which is closest in character to previous versions of STOPS. Trip generation and distribution estimates are developed from the US Census Bureau's Census Transportation Planning Package (CTPP) Journey-to-Work (JTW) flows, with a conventional mode choice model used to estimate transit mode shares. Incremental mode is applicable in regions that have detailed rider survey data, where mode shares and trip patterns can be derived from revealed travel behavior. Special market mode allows STOPS to be used in cases that cannot support incremental analysis, but still need to account for significant non-work trips associated with destinations such as hospitals and universities. In this mode, trips specific to the special markets can be included in the model to supplement CTPP data [225].

[16] 49 CFR Part 611.

STOPS synthetic uses standard, readily available public datasets to derive inputs for its model. As mentioned above, CTPP JTW flows are used to develop person trip tables, optionally updated to account for user-specified current and future year demographic growth. Since the primary concern of STOPS is transit ridership, highway network conditions are not explicitly modeled within the system and are instead obtained from metropolitan planning organizations (MPOs). Specifically, MPOs provide TAZ system information, employment and population estimates and forecasts, and interzonal highway travel time and distance estimates.

Transit levels of service including zone-to-zone waiting, access, in-vehicle, and egress times are created from local GTFS data. Mode choice models internal to STOPS, estimated using data gleaned from multiple cities across the United States, are used to estimate modal splits at each origin under existing, no-build, and build conditions and changes in VMT are estimated using shares of CTPP-observed trips [225].

Example Application: Nashville, TN

STOPS was applied to assess the ridership implications of "Let's Move Nashville," a public transit investment plan for the metropolitan Nashville region in Tennessee [226]. Nine high-capacity transit corridors were identified that included both bus rapid transit and light rail modes. Ridership forecasts for each of the high-capacity corridors were developed using STOPS. The model was calibrated to regional conditions, with input data corresponding to 2015. The technical memo accompanying the plan describes required data sources [227]. The Nashville Area MPO's travel demand model was a key source, providing information on population, employment, and highway travel times for current (2015), build (2040), and no-build (2040) conditions. GTFS data came from the Nashville Metropolitan Transit Authority/Regional Transportation Authority of Middle Tennessee, and weekday unlinked transit trip information from the agencies was used as additional input to the STOPS model.

Transit Boardings Estimation and Simulation Tool

The Transit Boardings Estimation and Simulation Tool (TBEST) is scenario planning and analysis software developed by the Florida Department of Transportation Office of Freight, Logistics and Passenger Operations [228]. First released in 2004, the tool was originally meant to help Florida transit agencies with short- and mid-term transit planning in the context of Transit Development Plans (TDPs) required by FDOT. It was designed to be scalable, incorporate service changes, and provide a standard method that could estimate ridership under TDPs [229]. Its scope has since been expanded to include a variety of additional utilities, including scenario modeling, service planning, assistance with grant applications, FTA Title VI service equity analysis, and market analyses [228].

At its core, TBEST is meant to assist in performance analysis by projecting ridership based on service adjustments, including changes in routes, fares, and demographics and land uses at origin and destination locations. The current objectives of the software include data integration at various jurisdictional levels, the ability to analyze services in relation to specific federal or state policies (such as Title VI, see Figure A-4), comparison of route structures and service alternatives, operational flows that are repeatable for efficiency, and the ability to quickly and easily communicate results to decision-makers [230]. The model works with socioeconomic growth data provided by the user, either as a system-wide growth rate or a zonal dataset.

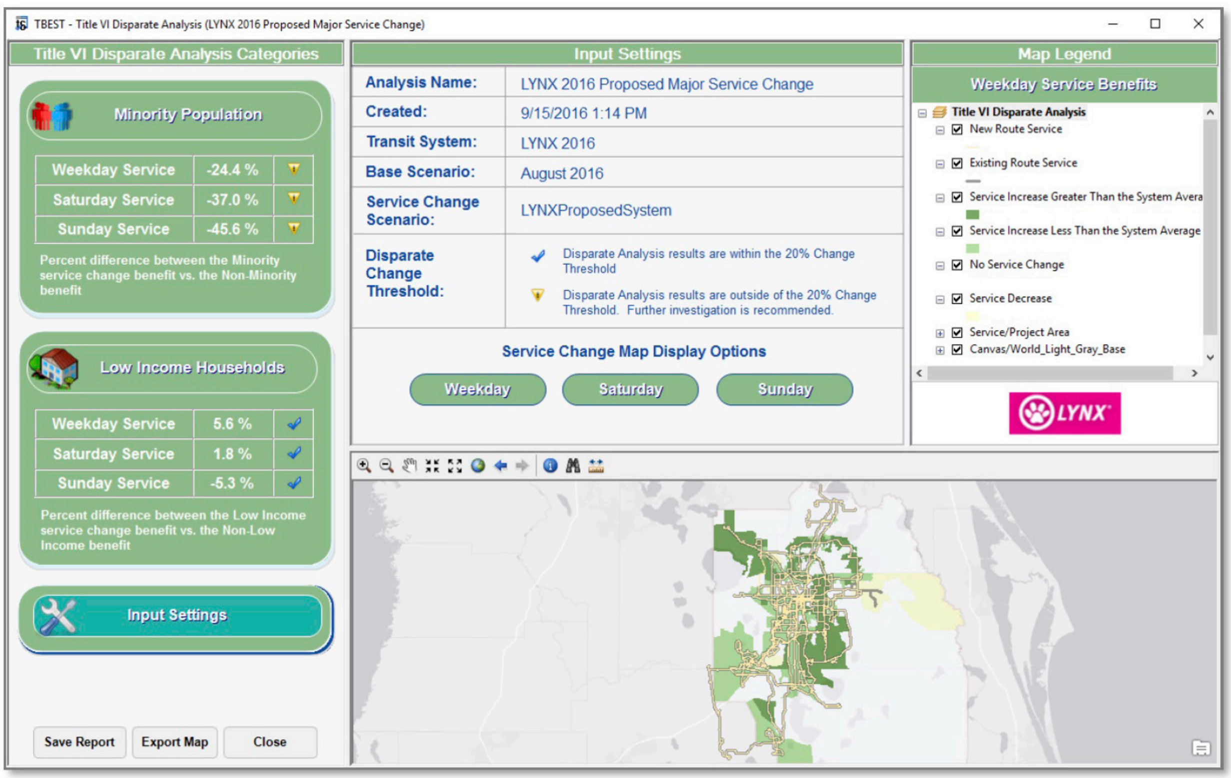


Figure A-4 *TBEST Title VI Disparate Analysis Dashboard*

Source: [231]

With integration across the state, estimation and comparisons are much easier to conduct. Reporting is simplified by having outputs designed to comply with federal, state, and local requirements. The centralization of the platform and data allow local agencies to function with limited capacity in terms of personnel or institutional knowledge. Data are maintained and updated centrally by FDOT, software improvements are centralized, and FDOT provides training for agencies and consultants. The tool is flexible in allowing for more localized scenarios, and it can be modified to other locations outside Florida as long as data sources are available (FDOT offers guidance and tools for locations outside Florida, but no technical assistance). More recent developments allow for inclusion of land use data at the parcel level, which can help analyze transit needs based on future growth or changes in development patterns.

TBEST is designed to capture access at the walk scale to and from transit, and capture accessibility via the transit network (this is the access to/via analyses). It accommodates demographic characteristics, transfers, service features like fare, speed, frequency, differences in route types, and differences in locations [229]. There are some limitations in the methodology used to estimate ridership. TBEST does not include the effects of auto travel in choice of transit ridership and does not respond to gas prices or auto travel costs. It does not include more subjective aspects of service quality such as cleanliness, comfort, and safety [229]. While feeder services can be accounted for, it does not account for park-and-ride services, and is not sensitive to rail [230].

The flexibility of the software allows it to be used in different scenarios and for different purposes. TBEST is in use by a majority of Florida transit agencies, with certain agencies using their own capacity to expand its capabilities. Central Florida Regional Transportation Authority (LYNX) in Orlando and Hillsborough Area Regional Transit Authority (HART) in Tampa both contributed to the various analysis engines in the TBEST tool. TBEST models are currently being calibrated for service planning at the local level by Utah Transit Authority (UTA) at Salt Lake City, Utah, and Cascades East Transit in Bend, Oregon [230].

University of Minnesota Accessibility Observatory

The Accessibility Observatory is a program of the University of Minnestota's Center for Transportation Studies [232]. The observatory produces the *Access across America* reports each year, ranking accessibility to jobs by transit in multiple cities across the United States. Some of their data are available to be freely downloaded. Their 2014 report on public transit, for example, evaluated accessibility in 46 of the 50 most populous metropolitan regions. The data are available online under a Creative Commons license [233].

Fundamentally, the Accessibility Observatory reports present the results of calculating cumulative opportunities accessibility measures during the morning peak period for automobile, public transit, and walking. Not all modes are available for all years, and results are presented for thresholds that vary from 10 minutes to one hour. The work embodies a number of methodological improvements over earlier efforts, including the calculation of accessibility at minute-level resolution, the use of different thresholds, and the use of census blocks instead of larger spatial units [234]. The adoption of a "worker-weighted" accessibility measurement is also promising and ensures that the regional performance measures reflect the experiences of average residents. Maps are also provided that use the same scale across all cities/regions so that side-by-side comparisons are possible. The use of the same scale across all maps is a limitation, since places with greater job totals are more likely to achieve higher accessibility rankings, all else equal.

While potentially a powerful tool for comparative studies across metropolitan regions or for an individual seeking to understand regional conditions, the results produced by the Accessibility Observatory are less useful from a public transit provider's perspective. The results reflect average existing conditions during the morning peak period for a single type of accessibility measure calculated at the census block level. There is no link to specific transit routes and there is no way to interact with the underlying performance measures. The raw data could be used to understand the demographic characteristics of locations experiencing poor transit service and that might be amenable to improvements, but no demographic breakdown of the results has been offered to date. The data also lend themselves well to further comparisons between automobile, public transit, and walking accessibility to determine locations with high *relative* performance; in other words, those locations where public transit provides levels of service that can compete with the automobile or where pedestrians enjoy relatively high accessibility because automobile travel is so congested. A final limitation with respect to the goals of the present study is that cumulative opportunity measures represent merely the potential for movement rather than information about how current or future transit users are traveling or can potentially benefit from a system.

Sugar Access

Sugar is proprietary transportation modeling and accessibility software developed by Citilabs and implemented with ESRI ArcMap. Sugar offers two main transportation solutions: Sugar Access, which is a tool that users can employ to define and analyze accessibility for their region, and Sugar Network Editor, which helps agencies better design and manage their transportation networks and logistics [235]. The model includes data from multiple sources. Roadway and pedestrian network information, as well as points of interest, come from HERE data and GTFS feeds are used for transit agency route and schedule data and synced to the roadway networks. Local data and information can also be incorporated into the tool and its outputs [236].

Sugar Access provides users with indicators such as travel times from single origins to multiple destinations and summaries by type of destination and mode [235]. A key output of the Sugar Access Tool is the "Access Score." Users can define weighted access scores across the different modes (driving, transit, biking, and walking) and to multiple destinations (assigning different scores to each if desired) to arrive at a more holistic idea of accessibility for their locations. Decay rates for each mode of transportation can be adjusted for the local context. The default decay rates are "taken from observed travel behaviors and represent the rate at which willingness to use a particular mode of transportation drops off based on time and/or distance" [237]. Figure A-5 shows an example results figure from Sugar Access displaying access scores for Milwaukee, WI.

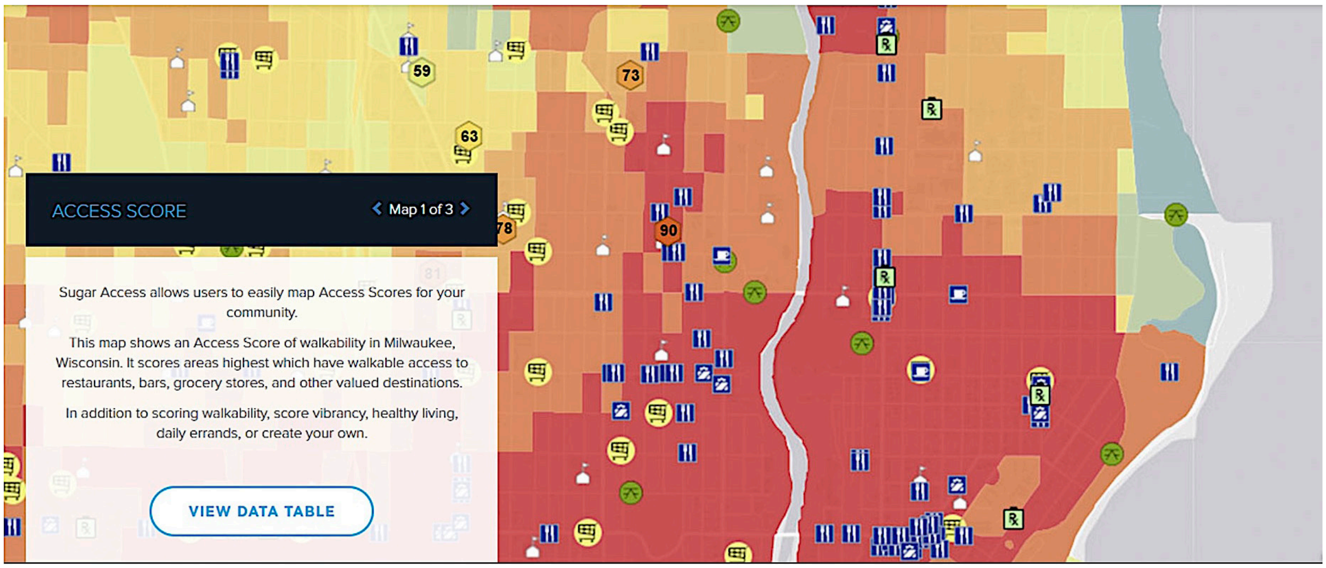


Figure A-5 *Example map showing access score for Milwaukee, WI*

Source: [236]

Example Application: Virginia Smart Scale Project Prioritization

Sugar Access was used by the Commonwealth of Virginia to prioritize transportation projects for funding under its "Smart Scale" project prioritization process [238]. Specifically, Sugar Access was used to score and evaluate projects based on three accessibility measures: access to jobs, access to jobs for disadvantaged persons, and access to multimodal choices [239]. An example application of Sugar Access in the Smart Scale context is shown in Figure A-6.

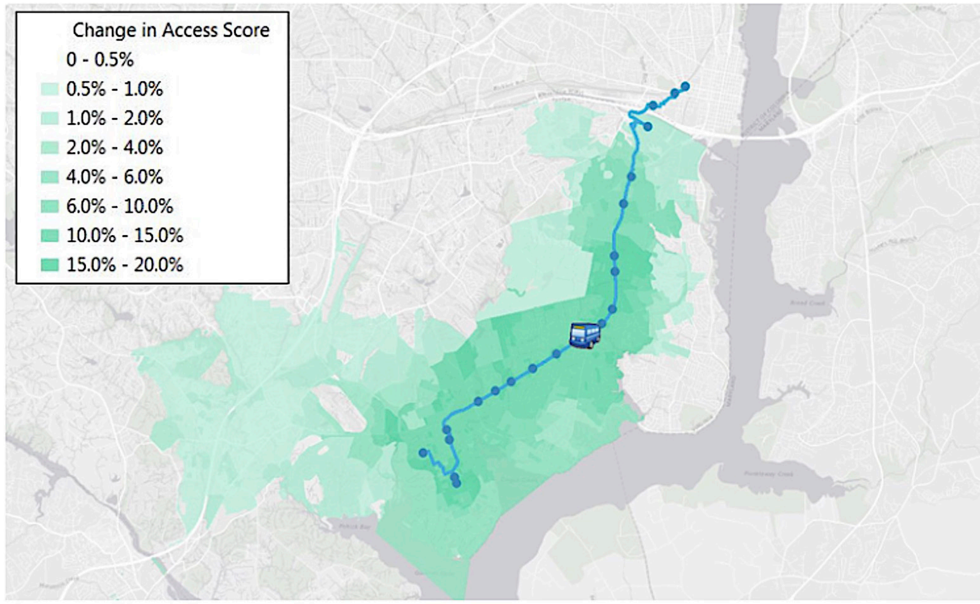


Figure A-6 *Multimodal analysis of increased access to jobs via new bus-only lane in Alexandria, VA*

Source: [239]

Conveyal Analysis

Conveyal Analysis is a web-based application used to create, edit, and analyze public transit accessibility [240]. The precursor to Analysis was called Transport Analyst. It was first announced in 2015 and was originally developed in collaboration with the World Bank to "create analysis and data management tools in support [of] improved transportation outcomes in cities around the globe" [241]. All of Conveyal's code is freely available and open source,[17] but they also offer consulting, support, and maintenance services for a fee. Establishing a working installation of Analysis would likely be quite challenging without Conveyal's support. Clients to date include Portland's TriMet, the New York Regional Plan Association, and the MIT Mobility Futures Collaborative [242].

The software relies heavily upon GTFS feeds, and other Conveyal software facilitates GTFS editing. Population and employment data and pedestrian network data are typically cleaned from the US Census Bureau's LEHD LODES and OpenStreetMap, respectively. For locations outside the United States, job location data must be uploaded by the user. Any other destination locations/types will also need to be uploaded by the user for analysis [243]. Multiple transport scenarios can be created and modified, and users can add and remove trips and stops, as well as adjust speed, dwell time, and frequency [244].

[17] https://github.com/conveyal

A unique feature of the Analysis software is its use of isochrone maps to represent accessibility from user-selected origin points in a region, with colors changing for each subsequent scenario. This type of comparison is illustrated in Figure A-7. It shows a “baseline” scenario based on input GTFS data (with accessible areas shown in red using a 60-minute travel time threshold) and a comparison scenario based on a proposed service change (accessible areas shown in blue). Stacked percentile plots show cumulative accessibility distribution across travel time, reflecting variation in accessibility based on departure time.

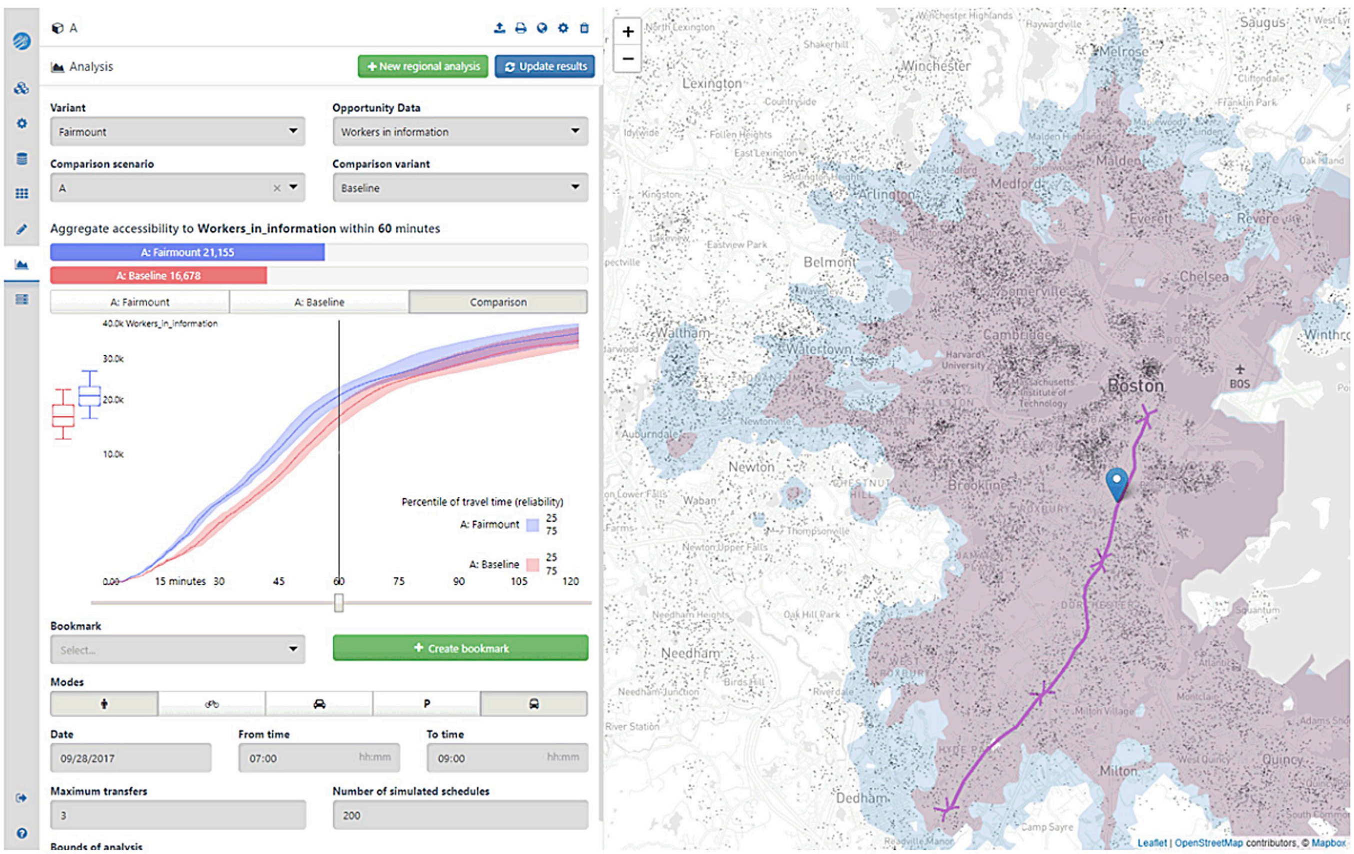


Figure A-7 *Comparing isochrones and distributions of workforce accessibility for two scenarios*

Source: https://www.conveyal.com/analysis/

The analysis allows some flexibility in terms of parameters. Users can choose to analyze access with or without transit and select walking, biking or driving as the mode. Date and time can be set, and a maximum transfer limit can be imposed [245]. Analysis also allows regional analyses where an accessibility calculation is repeated for each location within a defined grid. Regional analyses provide the average accessibility experienced at each location and could be used to generate regional comparisons of the type produced by the University of Minnesota Accessibility Observatory, for example. Figure A-8 shows the results of this type of analysis.

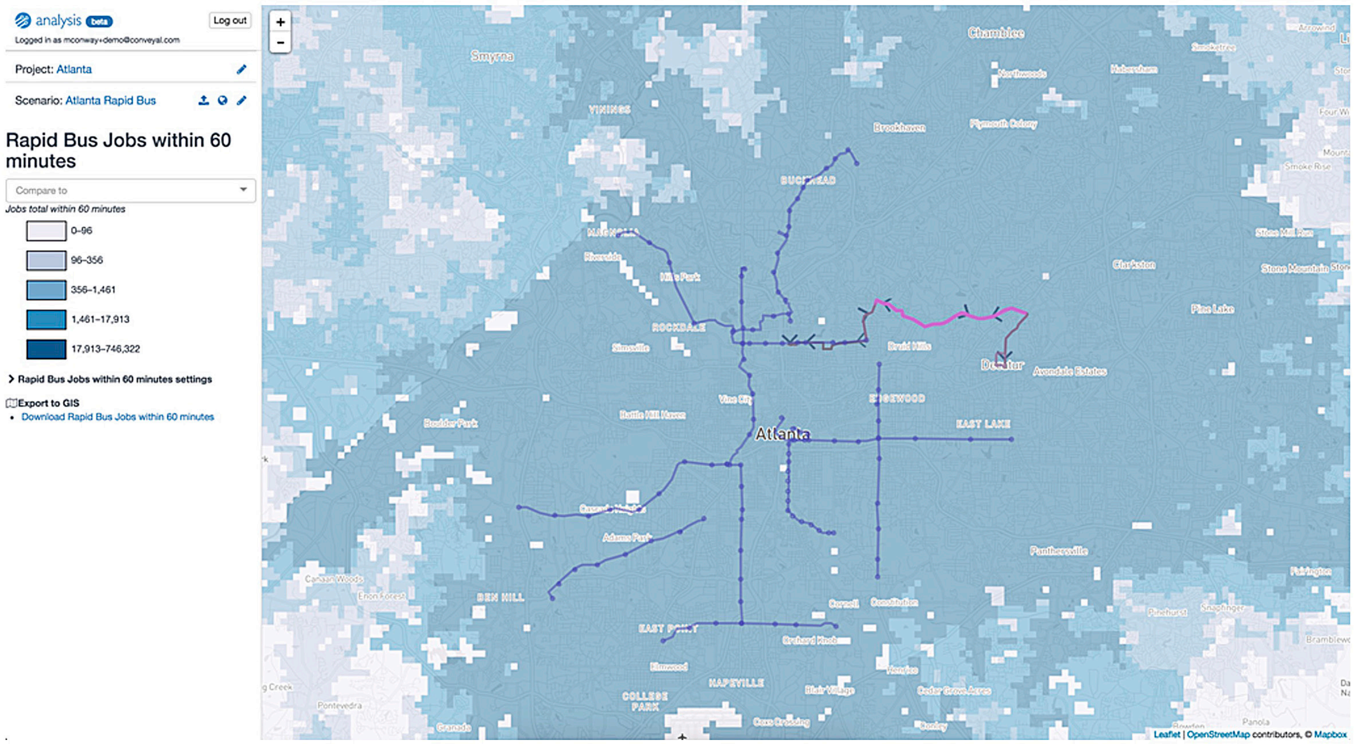


Figure A-8 *Conveyal Analysis regional results*

Source: http://analysis-ui.readthedocs.io/en/latest/analysis/regional/

Remix

Remix is a proprietary cloud-based application for public transit planning. Remix provides its clients the ability to see immediate effects of public transit service changes designed on the fly. As a new route is drawn, Remix generates information on fleet requirements, operating cost, and route miles, as well as population and jobs within defined buffers near the route [246]. A primary goal of the tool is to quickly visualize trade-offs that can be used in decision-making and for communication and outreach. Isochrones are used to depict locations reachable within specific travel time thresholds from a user-selected origin. The tool uses Open Street Map (OSM) as a base for all street analysis and GTFS feeds to describe transit routes and schedules. US census data can be overlaid to quantify the groups potentially affected by transit planning decisions.

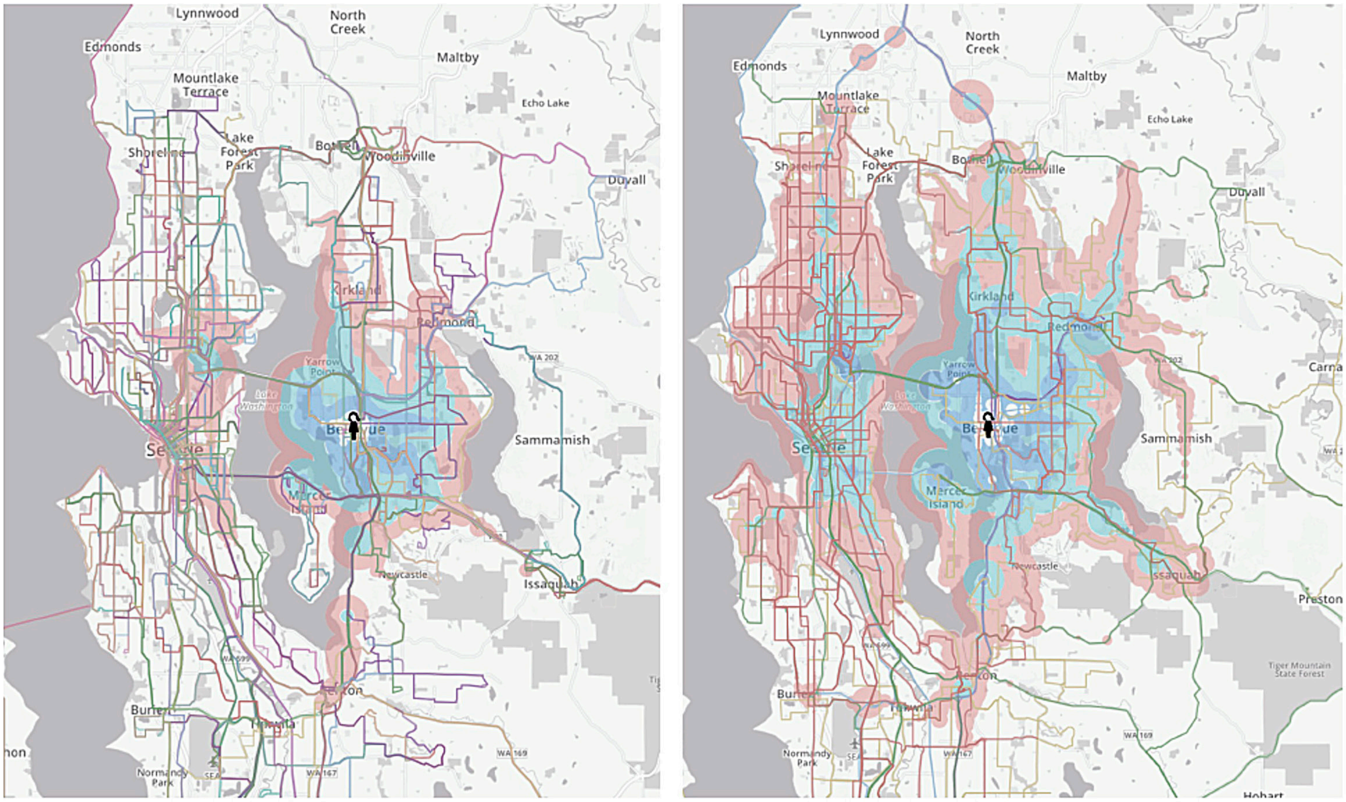


Figure A-9 *Travel time isochrones for downtown Bellevue, WA, in 2016 (left) and 2040 (right)*

Remix is currently used by more than 225 transit agencies worldwide [247], most commonly for system redesign, planning around scheduled detours or rerouting, and for public engagement [248]. Customers report reduced time and effort, being able to quickly compare scenarios, easily represent the implications of specific decisions, and understand the relative costs and benefits of multiple choices. Remix clients work with a "Customer Success Manager" to add custom data to their platform (e.g., stop-level ridership data, or land use or future population data) or to design bespoke analyses [249]. The use of OSM can also cause problems for agencies or jurisdictions with their own base map layers that might require realignment [250]. Remix uses open-source software tools but does not make their original software or code freely available.

Example Application: Puget Sound Regional Council

The "Regional Access to Remix Transit Sketch Planning" project tested Remix in the context of collaborative transit planning in the central Puget Sound region [250]. Nine agencies in the region worked together to create an integrated 2040 transit network incorporating the latest plans from each. Individual agencies also assessed questions of interest:

- Pierce Transit (Pierce County, Washington) used Remix to explore system-level trade-offs and performance of alternative scenarios for their fixed-route service.
- Community Transit (Snohomish County, Washington) used Remix to evaluate alternative route and network configurations in their fall 2017 and spring 2018 service change plans.
- Sound Transit (Seattle Metropolitan Area) used Remix to design detours and re-routes for its bus loops.
- In King County Metro's long-range plan, Metro CONNECTS, Remix was used to evaluate alternative 2040 network scenarios and to present performance evaluation results to stakeholders using travel time isochrones.

Remix was also used to coordinate planning and minimize duplication of service between Pierce Transit and King County Metro. Finally, Pierce Transit and Community Transit both used Remix to perform a Title VI service equity analysis as required by FTA guidance [4]. Tabular results for the analysis conducted by Pierce Transit are shown in Figure A-10. The analysis relies on census demographics within 1/4-mile Euclidian buffers around all stops that compose a route before and after proposed changes.

	Before				After				Difference				
Route	Population (within 1/4 mi)	Low Incom	Minor	Trips (Annually)	Population (within 1/4 mi)	Low Incom	Minor	Trips (Annually)	People-Trips (Population * Trips)	Low Income People-Trij	Minority People-Trips	Change Borne By Low Income	Change Borne by Minoritie
4 112th St	17,224	19.4%	39.4%	9,685	17,224	19.4%	39.4%	9,920	4,392,120	850,842	1,730,175	19.4%	39.4%
10 Pearl Street	14,689	16.9%	29.6%	7,220	14,584	17.0%	29.7%	8,750	21,380,420	3,723,956	6,481,600	17.4%	30.3%
11 Pt. Defiance	23,638	18.3%	25.9%	3,940	23,755	18.1%	22.8%	7,765	91,323,855	16,344,994	17,821,450	17.9%	19.5%
13 N. 30th Street	11,159	19.5%	27.5%	3,790	0			0	-42,292,610	-8,227,134	-11,623,930	19.5%	27.5%
14 N. Proctor District	16,944	23.1%	23.7%	3,790	0			0	-64,217,760	-14,805,503	-15,228,220	23.1%	23.7%
16 Ups / Tcc	22,263	17.6%	25.4%	4,980	22,313	17.3%	25.9%	9,315	96,975,855	16,545,108	25,708,500	17.1%	26.5%
28 S 12th St	17,055	21.4%	41.3%	6,710	16,318	21.1%	40.9%	7,220	3,376,910	339,848	816,820	10.1%	24.2%
41 Portland Ave	12,011	33.7%	60.9%	7,385	15,629	28.0%	49.1%	9,170	54,616,695	10,293,272	16,327,150	18.8%	29.9%
42 McKinley Ave	12,422	21.5%	53.4%	4,415	12,287	21.5%	53.1%	8,495	49,534,935	10,681,019	26,128,525	21.6%	52.7%
45 Yakima	25,668	25.7%	45.6%	4,560	25,668	25.7%	45.6%	8,640	104,725,440	26,955,969	47,793,120	25.7%	45.6%
48 Sheridan M St	24,169	25.3%	53.6%	7,640	28,663	27.4%	53.8%	9,425	85,497,615	27,349,909	46,264,335	32.0%	54.1%
51 Union Ave	26,923	22.3%	43.3%	4,615	0			0	-124,249,645	-27,747,704	-53,838,590	22.3%	43.3%
52 TCC Tac Mall	9,800	21.4%	42.6%	8,680	28,807	24.1%	51.6%	9,190	179,672,330	45,478,895	100,287,640	25.3%	55.8%
53 University Place	31,410	18.3%	37.6%	4,670	21,601	15.2%	36.1%	8,750	42,324,050	1,941,770	13,069,870	4.6%	30.9%
54 38th St	16,300	22.4%	48.3%	8,240	0			0	-134,312,000	-30,036,652	-64,914,720	22.4%	48.3%
55 Parkland Tac Mal	19,486	25.5%	55.8%	8,790	0			0	-171,281,940	-43,729,800	-95,600,040	25.5%	55.8%
56 56th St	13,961	22.2%	51.9%	4,215	16,031	28.2%	55.9%	8,040	69,959,325	23,260,923	41,467,005	33.2%	59.3%
57 Tacoma Mall	15,454	28.6%	47.2%	7,985	15,382	28.6%	47.2%	8,495	7,269,900	1,960,630	3,463,560	27.0%	47.6%
202 72nd Street	12,848	20.0%	53.2%	9,465	12,965	20.2%	53.2%	9,720	4,607,880	1,144,493	2,424,600	24.8%	52.6%
206 Pacific Hwy / Tillicum / Ft. Lewis	10,383	33.7%	57.7%	7,770	11,311	35.1%	59.9%	9,555	27,400,695	10,696,283	18,129,510	39.0%	66.2%
212 Steilacoom	8,643	15.7%	37.6%	8,535	8,643	15.7%	37.6%	8,790	2,203,965	346,855	827,985	15.7%	37.6%
214 Washington	9,649	13.0%	40.2%	8,040	9,649	13.0%	40.2%	8,550	4,920,990	640,590	1,980,330	13.0%	40.2%
300 S Tacoma Way	14,900	28.9%	57.9%	8,150	0			0	-121,435,000	-35,142,703	-70,293,750	28.9%	57.9%
400 Puyallup / DowntownTacoma	9,236	17.8%	23.8%	6,375	9,236	17.8%	23.8%	6,630	2,355,180	418,780	559,470	17.8%	23.8%
402 Meridian / Federal Way	15,317	12.0%	24.9%	7,075	15,317	12.0%	24.9%	8,860	27,340,845	3,270,158	6,815,130	12.0%	24.9%
500 Federal Way	4,113	27.1%	36.6%	8,245	4,113	27.1%	36.6%	9,775	6,292,890	1,706,204	2,301,120	27.1%	36.6%
All Changes	294,085	18.1%	39.2%	249,290	287,320	18.1%	39.2%	249,400	198,274,400	36,976,467	55,800,945	18.6%	28.1%

	Low Income	Minority
Change Borne By	18.6%	28.1%
Area Average	14.3%	35.3%
Delta	4.4%	-7.1%

Figure A-10 *Snapshot of Pierce Transit's Title VI analysis by Remix*

Note: This table shows all routes expected to experience a change in weekday span and the demographics within buffers around stops.

Appendix B

Advisory Groups

Two types of groups were formed to guide the project and provide periodic feedback on the recommendations, the Community Advisory Group and the Technical Advisory Group. These groups offered valuable input to the project, helping to keep the focus on underserved populations and guide the final recommendations toward tools and measures useful for a wide variety of agency expertise.

Community Advisory Group

Membership

The project team and representatives from the Federal Transit Administration guiding the project submitted ideas for possible Community Advisory Group (CAG) members. The goal was to find individuals who represented various components of the transit user community who are often underrepresented or impacted by service changes in a non-productive manner. In order to support participation by the community-based group representatives, it was decided that CAG members would be offered a stipend of $1,000 for their participation, limiting membership to no more than 10. Prior to agreeing to participate, CAG members had to verify that the agency they represent was also not involved in any current or anticipated disputes with FTA. Striving for a mix of public agency staff and nonprofit organization representation, an initial list of possible members/agencies were identified and are listed below:

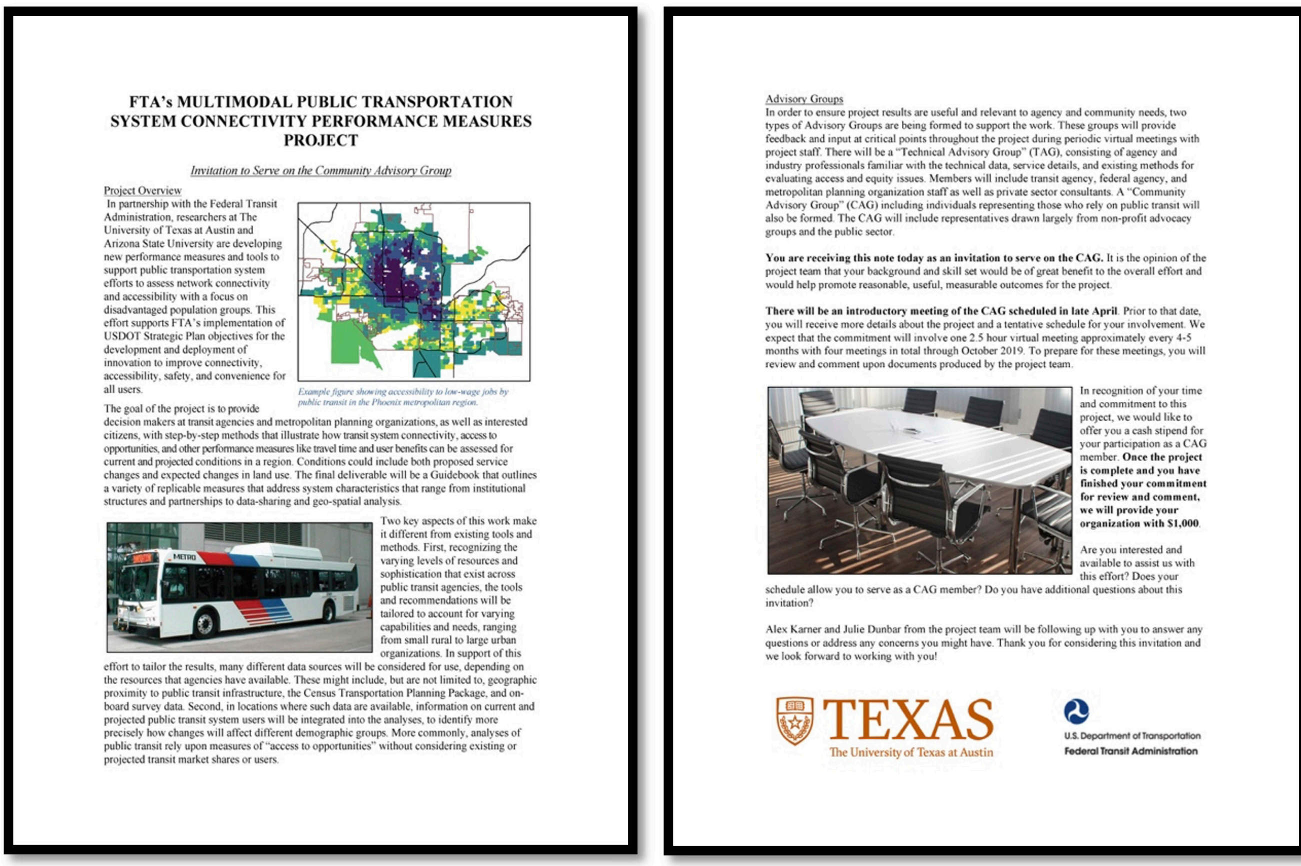
- Richard Marcantonio, Public Advocates, Inc.
- Nathaniel Smith, Partnership for Southern Equity
- Karyn Rotker, ACLU Wisconsin
- Simran Noor, Race Forward
- Anita Cozart, PolicyLink - Established the Transportation Equity Caucus
- The Leadership Conference on Civil and Human Rights
- Oni Blair, Link Houston
- Carol Tyson, Government Affairs Liaison at Disability Rights Education and Defense Fund (DREDF)
- Billy Altom, Association of Programs for Rural Independent Living
- Jana Lynott, AARP
- Rebecca Cokley, National Council on Disability
- Dara Baldwin, National Disability Rights Network
- Representative from the Community Transportation Association of America (www.ctaa.org)

- Shelley Poticha, National Resources Defense Council
- Paul Aldretti, Mile High Connects (a Denver-based advocacy group concerned with transit issues, especially access for low-income people)

RailVolution's National Steering Committee now has nonprofit agencies represented. Possible candidates for CAG are:

- Craig Edleman, Low-Income Investment Fund in San Francisco
- Richard Mans, Local Initiatives Support Committee in NYC
- Melinda Pollack, Enterprise Community Partners in Denver

An overview of the project and invitation for participation were prepared and circulated. Figure B-1 shows the CAG invitation.



FTA's MULTIMODAL PUBLIC TRANSPORTATION SYSTEM CONNECTIVITY PERFORMANCE MEASURES PROJECT

Invitation to Serve on the Community Advisory Group

Project Overview

In partnership with the Federal Transit Administration, researchers at The University of Texas at Austin and Arizona State University are developing new performance measures and tools to support public transportation system efforts to assess network connectivity and accessibility with a focus on disadvantaged population groups. This effort supports FTA's implementation of USDOT Strategic Plan objectives for the development and deployment of innovation to improve connectivity, accessibility, safety, and convenience for all users.

Example figure showing accessibility to low-wage jobs by public transit in the Phoenix metropolitan region.

The goal of the project is to provide decision makers at transit agencies and metropolitan planning organizations, as well as interested citizens, with step-by-step methods that illustrate how transit system connectivity, access to opportunities, and other performance measures like travel time and user benefits can be assessed for current and projected conditions in a region. Conditions could include both proposed service changes and expected changes in land use. The final deliverable will be a Guidebook that outlines a variety of replicable measures that address system characteristics that range from institutional structures and partnerships to data-sharing and geo-spatial analysis.

Two key aspects of this work make it different from existing tools and methods. First, recognizing the varying levels of resources and sophistication that exist across public transit agencies, the tools and recommendations will be tailored to account for varying capabilities and needs, ranging from small rural to large urban organizations. In support of this effort to tailor the results, many different data sources will be considered for use, depending on the resources that agencies have available. These might include, but are not limited to, geographic proximity to public transit infrastructure, the Census Transportation Planning Package, and on-board survey data. Second, in locations where such data are available, information on current and projected public transit system users will be integrated into the analyses, to identify more precisely how changes will affect different demographic groups. More commonly, analyses of public transit rely upon measures of "access to opportunities" without considering existing or projected transit market shares or users.

Advisory Groups

In order to ensure project results are useful and relevant to agency and community needs, two types of Advisory Groups are being formed to support the work. These groups will provide feedback and input at critical points throughout the project during periodic virtual meetings with project staff. There will be a "Technical Advisory Group" (TAG), consisting of agency and industry professionals familiar with the technical data, service details, and existing methods for evaluating access and equity issues. Members will include transit agency, federal agency, and metropolitan planning organization staff as well as private sector consultants. A "Community Advisory Group" (CAG) including individuals representing those who rely on public transit will also be formed. The CAG will include representatives drawn largely from non-profit advocacy groups and the public sector.

You are receiving this note today as an invitation to serve on the CAG. It is the opinion of the project team that your background and skill set would be of great benefit to the overall effort and would help promote reasonable, useful, measurable outcomes for the project.

There will be an introductory meeting of the CAG scheduled in late April. Prior to that date, you will receive more details about the project and a tentative schedule for your involvement. We expect that the commitment will involve one 2.5 hour virtual meeting approximately every 4-5 months with four meetings in total through October 2019. To prepare for these meetings, you will review and comment upon documents produced by the project team.

In recognition of your time and commitment to this project, we would like to offer you a cash stipend for your participation as a CAG member. **Once the project is complete and you have finished your commitment for review and comment, we will provide your organization with $1,000**.

Are you interested and available to assist us with this effort? Does your schedule allow you to serve as a CAG member? Do you have additional questions about this invitation?

Alex Karner and Julie Dunbar from the project team will be following up with you to answer any questions or address any concerns you might have. Thank you for considering this invitation and we look forward to working with you!

Figure B-1 *Project overview and CAG invitation*

After several attempts to reach these individuals, seven people with two alternates agreed to serve on the CAG for the project. Table B-1 shows the list of CAG members and their associated agency representation.

Table B-1 *Community Advisory Group Membership*

Name	Agency
Agency Type: Nonprofit/Other	
Anita Cozart	Policylink
Richard Marcantonio	Public Advocates, Inc.
Nathaniel Smith	Partnership for Southern Equity
Karyn Rotker	ACLU Wisconsin
Oni Blair	LINK Houston
Jonathan Brooks	LINK Houston, alternate
Ashley Johnson	LINK Houston, alternate
Carol Tyson	Government Affairs Liaison at Disability Rights Education and Defense Fund (DREDF)
Billy Altom	Association of Programs for Rural Independent Living
Agency Type: Public Sector	
Naomi Doerner	City of Seattle

Meetings

A total of three meetings were planned for the Community Advisory Group. Two were held during the development of the work and one is to be scheduled at the close of the project (after this documentation is complete.) All meetings were held virtually using an online platform with meeting materials distributed prior to each, as appropriate.

Meeting #1 was held on April 30, 2018, and seven CAG members participated, along with project staff (Alex Karner, Julie Dunbar). The agenda/goals for the first meeting were to:

- Provide an overview of the project and its current status
- Hear from the CAG members about their constituents, their concerns, and how they can be reflected in this work
- Discuss potential missing pieces

The presentation slides used for the meeting are available here. Dr. Karner developed and presented this material and the comments, questions and suggestions from the CAG were recorded in meeting minutes, shown in Table B-2.

Table B-2 *Community Advisory Group Meeting Notes (April 2018 Meeting)*

CAG Member Comments/Questions	Staff Response
(Slide 8): Noted it is also important for community and user groups to be able to access the tools from the project so they are able to establish their own version of 'ground truth.'	
(Slide 3): Asked about the propensity to ride transit versus other modes of transportation?	We will consider a hierarchy of internal data and methods; we are focused on our measures showing impacts on specific users and modes (which the OnBoard Survey data will support). We don't want to have 'watered down' results at only a regional level. We hope to generate a spectrum of measures that show how some are 'better' than others, but if an agency doesn't have the OBS data, for example, there will still be recommendations to help them.
She supports the idea of cross modal comparisons (bus versus drive) as not all areas have abundant options	We understand that analyzing transit in a vacuum can sometimes be of little utility. It might be possible to include some cross-modal comparisons, but we might have to rely on "recommendations" for future work in the report.
(Slide 21): She pointed out that peak hour measures only capture access to a certain type of job; it misses the income level/job type of many of their constituents. She suggests we consider off-peak to get at the equity of 'real' transit users.	This is very reasonable. We hope to consider time of day, type of destination and actual user.
(Slide 24): The user benefit calculation does not help solve the 'auto versus transit' analysis asked about previously	
(Slide 25): He is not supportive of proximity-based analysis and supports the use of on-board survey data whenever possible.	We expect to show that proximity-based analysis does not measure up for evaluating connectivity. He also noted that many agencies have OBSurveys, but don't know how to make use of them outside the obvious model updates.
He pointed out the often-varying levels of quality between on-board surveys depending on the contractor used.	
He supports the idea of agencies having advanced data and tools but limited knowledge of how to fully use them. He commented that OBSurveys often reside with the regional agency (MPO) rather than the transit agency. Also TxDOT did a rural OnBoard Survey across regions and rural agencies recently; we might want to consider this as a resource as well.	
(Slide 20): She asked Alex to explain further the concept of moving from static to real time data.	Historically, transit analysis has been based on networks/ service levels developed from the paper route schedules. Now with real time data, we can include measure of reliability, timeliness, crowding and get away from using the 'perfect' world that a paper schedule reflects.

Table B-2 (cont.) *Community Advisory Group Meeting Notes (April 2018 Meeting)*

CAG Member Comments/Questions	Staff Response
Are we considering the user's perspective or just the researcher's perspective? Her constituents, for example, often have smart phones but do not have access to the real time info available through apps and such. The data divide of the under resourced community is real and something we should consider as we evaluate connectivity/equity.	We can definitely make real time data more available to the planner, but not going to be able to consider this from the actual user perspective here. But the issue will definitely be noted even if we can't solve it within this study framework.
He wondered about why we would select CUMTD if they have no survey data?	We purposely didn't want all of our beta test sites to have survey data so we wouldn't eliminate consideration of our process by other agencies without survey data right out of the gate. We will be able to have a true comparison of with and without survey data from both Houston Metro and Stanislaus.
He supports us including an agency without survey data.	
Regarding the map of Chicago; she finds it annoying that maps like this always tend to focus on the CBD when what we really need is to look at all the non-CBD job centers for the actual 'transit community'. She also asked if there's a way from the research perspective to capture drivers versus bus riders – she emphasized again that to her this comparison was important.	Many OBSurveys have companion household surveys done at the same time (i.e., Houston does). We hope to use this data to try to get at the drive versus transit comparison or at least try to identify the gap that exists here.
How is HGAC about sharing data? he is very familiar with HGAC and their data; their work with both HGAC and Metro has been very positive. But both agencies are chronically understaffed which can be the challenge. Chris VanSlyke and modeling staff at HGAC have an Activity Based Model and new data, but often are challenged in knowing the 'new ways' to use the data. Oni supported these comments	
Will the project be able to consider the disabled community of users as well (break them out specifically)?	Yes – especially for those areas with good OBSurvey data.
Often the survey data is the problem, as disabled rider data is not collected. Even if we can't get the data for the analysis, if we can at least identify the gaps that would be good Will we be looking at station accessibility (physical access at a stop)? Paratransit wait times and no show data are also very helpful and important. Cross walk and traffic light placement in relation to bus stops often are quite problematic for disabled users to access and most agencies completely miss these details in their planning.	Perhaps we can have a set of recommendations that aren't technical, but suggestions for agencies to consider to 'enlighten' their thinking. Not just another User Advisory Group but something more specific.
Rabbittransit shared ride comment – what are they doing exactly?	He believes they're deploying mobile technology but will get more information and report back next time.

Meeting #2 was held on November 9, 2018, and eight CAG members participated, along with project staff (Alex Karner, Julie Dunbar). This meeting included an update on project progress and again provided opportunity for CAG members to provide comments on the work to date. The meeting presentation slides can be found here and Table B-3 summarizes comments from CAG members.

Table B-3 *Community Advisory Group Meeting Notes (November 2018 Meeting)*

CAG Member Comments/Questions	Staff Response
(Slides 1-8): Will this be a cross modal analysis at some point?	It is likely our scope will limit our ability to get to this, but it can definitely be part of the final recommendations for future study. Data related issues make looking at auto access even more challenging. GTFS travel time data is free, but auto travel information comes via private vendors for a significant cost.
(Slides 1-8): As service redesign projects take place, another avenue to be aware of is the introduction of 'tap' onboarding systems that are meant to speed things up at a given station, but are cashless (potentially causing restricted use for low income riders) and often difficult to enforce. Will we be able to investigate this impact?	We will evaluate stop consolidation issues, but fare media and enforcement is likely outside our scope. This can also be included in the 'further study' section of the final report.
(Slides 1-8): Are hours of operation included in accessibility analysis?	Yes, following slides touch on this, but generally the data available for our analysis does allow for multiple times of day (not just the peak).
(Slide 18): Does STOPS include all trip purposes? Are the demographics used in STOPS weighted towards certain folks tendency to ride?	Yes, STOPS includes all weekday trip purposes and has a mode choice component to measure transit trip propensity.
(Slide 18): How do you know STOPS is accurate?	FTA has done extensive validation of STOPS using observed data. STOPS has options for using CTPP (Census Transportation Planning Package) data from 2010 or a local agency On Board Survey Data. OBS Data provides an even more accurate picture for STOPS to validate to, resulting in more current and accurate results.
Does STOPS just do current day rider estimates?	STOPS has the ability to evaluate future scenarios and added riders resulting from proposed improvements. If STOPS is not an option, our analysis would only be able to work with current riders from CTPP or OBS data inputs. Alex (slide 19): Please note that not every data source can address every outcome or measure. Part of this project is to investigate different data sources and show how they compare over a variety of measures.
Houston's redesign has actually impacted people with disabilities; they are often lumped into paratransit but they actually used the regular bus and now cannot. Also has implications for elderly population as they are not able to walk to the 'newly consolidated' bus stop if it's further away.	One limit of using current rider data is that it does not include potential users if the service is different, but it is clearly important.

Table B-3 (cont.) *Community Advisory Group Meeting Notes (November 2018 Meeting)*

CAG Member Comments/Questions	Staff Response
More trips would definitely occur if the potential rider could access the system. (Oni referenced Houston Metro Board meeting discussions on this and will provide links to Project Team for reference).	
Houston Metro did an assessment for ALL stops accessibility, perhaps we should see if they will share that data with the Project Team?	Alex will inquire.
Access may be there but the actual 'accessibility' is different and often overlooked for persons with disabilities.	We will bring this up on our next Project Team call with FTA to brainstorm ways it might be more fully included in our analysis.
Challenge for certain things she'd like to see evaluated where data is not available: • The ability to look at route cuts, accessibility (elevators, ramps, actual physical station design); sidewalk access is often the hardest part. (Alex: sidewalks are a big issue but so is the data availability to evaluate the impacts; can be included in further study recommendations) • The ability to consider demographics of who uses paratransit along a certain route, with consolidation walk/roll distances can be significantly impacted; • Will affordable housing and access to it be considered? (Alex: Yes, are there specific types to be included (ie. Section 8, etc.) or just general?) • Response to service cuts points to walk/drive impacts, but can also result in isolation and greater social exclusion for some. Can this be included in the analysis? (Alex: perhaps we can drill down into greater detail in areas where cuts have occurred to look at the specific impacts for persons with disabilities)	
Will we include first/last mile options in our connectivity analysis? Will we be evaluating access to other services besides just jobs?	In general, all of our work will be multimodal and provide connectivity options via transfer, etc. Our ability to include TNC's or private first/last mile options may be challenged by the project scope, but we do include walk/drive to transit access.
Will we be collecting data to 'ground truth' our models and outcomes?	On Board Survey data is the best form of 'ground truth' and STOPS is validated against this data for accuracy in forecasting. It will be important for us to have measures that are closely linked to people/riders and their needs. We will imbed ground truth into our work and a primary purpose of the CAG is keep the project team accountable.
Will there be any discussion of this project at TRB? What's the project timeline again?	This is a 2-year project and we are closing out year 1. The next year will be focused on implementation of potential methods and measures. Alex will be at TRB, presenting our analysis to date in a poster session. He will transmit details to the CAG. He is also hoping to present at ACSP and TRB Transportation Planning Applications Conferences in 2019.

Table B-3 (cont.) *Community Advisory Group Meeting Notes (November 2018 Meeting)*

CAG Member Comments/Questions	Staff Response
Will we present any contextual challenges on how to actually get transit providers to step up and use this analysis framework in their decision-making	This would be a goal, but in actuality it will depend on the feedback we get from the beta test sites. The data intensive part of the approach is out of reach for many small to mid-sized agencies, but we hope to include options for all sized agencies to improve their accessibility analysis in some way.
Disconnect between modeling and agency's approach to paratransit. There seems to be a push to get people off paratransit due to the cost, but it's rarely included in modeling and fixed routes that are included in modeling are not often accessible to paratransit users.	GTFS data is available to the individual stop and indicates if it is wheelchair accessible, in some cases. Often the data field is blank, but he could try to consider wheelchair users where we do have data to see how they are impacted (similar to the analysis by race).

Summary

Input from the CAG was logged carefully in the notes from each meeting. It was clear from discussions at both meetings that the issues related to accurately measuring impacts on the low-income, transit-dependent populations vary widely and many were outside the scope of the analysis for this project. However, it is important to make note of those that could be part of future work on this issue. Key points of note are:

- Suggestion to ensure the tools developed for this work are made available to the broader public, not just the transit agencies to allow users to establish their own expectations.
- Suggestion to include cross-modal comparisons, not just among transit modes, but with drive alone as well. The motivation for this is that not all who fall into the low-income, underserved population group have access to transit and would, therefore, not show up in an analysis based on onboard survey data.
- Suggestion to be sensitive to the types of jobs measured in a peak hour analysis as that completely misses the income level/job type of many low income/ disadvantaged populations.
- Caution that just because an agency has onboard survey data, does not mean they have the knowledge to use it effectively. This emphasizes the need for clear direction guiding the application of the measure from the project.
- Caution that the data divide of the under-resourced community is an important issue (e.g., the unavailability of smart phones.) This lack of access could result in underrepresentation in survey data collected and in the use of route planning apps. Also, the unavailability of smart phones could limit opportunities for low-income riders to use the cashless "tap" onboarding systems that are becoming commonplace.

- Caution against CBD centric analysis as there are many non-CBD job centers that should be included to get a full picture of the potential transit community.
- Suggestion to broaden the discussion of accessibility to include station accessibility features. For example, cross walk and signal placement in relation to bus stops are often quite problematic for disabled users and agencies often overlook this aspect of "accessibility." Often disabled users are lumped into the paratransit category, but many can and do use the regular transit system but their unique requirements for access don't always show up in a survey. The project should acknowledge the difference between "access" and "accessibility" for persons with disabilities.
- Suggestion to be mindful of the isolation and social exclusion impacts that can also result from service cuts, not just walk/drive demand impacts.
- Suggestion to include assessment of first/last mile connectivity to more than just jobs as the under resourced community often relies on transit for more than job access.
- Suggestion to address the contextual challenges of how to get transit providers to actually step up and use the more robust analysis framework presented in the Project as part of their decision-making.

Technical Advisory Group

Membership

The project team and representatives from the Federal Transit Administration guiding the project submitted ideas for possible Technical Advisory Group (TAG) members. The goal was to identify a wide range of individuals with expertise in:

- Public transit performance analysis
- Travel demand modeling
- Public transit data sources
- Accessibility modeling
- Title VI/EJ considerations

After some discussion, the individuals listed in Table B-4 were invited to participate.

Table B-4 *Technical Advisory Group Invitees*

Name	Organization	Alternate	Organization
Agency Type: Private Sector			
Anson Stewart	Conveyal	David Emory	Conveyal
Paul Supawanich	Remix		
Frank Hebbert	Motivate		
Elizabeth Sall	Urban Labs LLC		
Christof Spieler	Huitt-Zollars		
Agency Type: Public Sector			
Brian Gardner	FHWA		
Supin Yoder	FHWA		
John Thomas	EPA		
Josh Geyer	HUD		
John Orr	Atlanta Regional Commission		
Christina O'Claire	King County, WA		
Greg Krykewycz	Delaware Valley Regional Planning Commission (DVRPC)		
Alan Lehto	TriMet		
Agency Type: Academic			
Steve Polzin	CUTR	Dennis Hinebaugh	CUTR
Graham Currie	Monash University		
Yingling Fan	University of Minnesota		
Andrew Owen	University of Minnesota		
Agency Type: Nonprofit/Other			
Adie Tomer	Brookings		
Rich Weaver	APTA		

An invitation similar to that used for the Community Advisory Group (see Figure B-1) was sent to these individuals, however the TAG members were not offered a stipend for their participation. Given schedules and other commitments, the individuals shown in Table B-5 served as the Technical Advisory Group for the project.

Table B-5 *Technical Advisory Group Membership*

Name	Agency
Private Sector	
Brian McCollom	McCollom Consulting
Anson Stewart	Conveyal
Paul Supawanich	Remix
Frank Hebbert	Motivate
Elizabeth Sall	Urban Labs LLC
Christof Spieler	Huitt Zollars/Houston
Public Sector	
Brian Gardner	FHWA
John Thomas	EPA
Josh Geyer	HUD
Lee Cryer	Denver RTD
Chaushie Chu	Los Angeles Metro
Shayna Pollock	Atlanta Regional Commission
Greg Krykewycz	Delaware Valley Regional Planning Commission
Grant O'Connell	TriMet
Lucien Bruno	King County Metro
Academic	
Steve Polzin	CUTR/University of South Florida
Graham Currie	Monash University
Yingling Fan	University of Minnesota
Andrew Owen	University of Minnesota
Nonprofit/Other	
Rich Weaver	APTA

Meetings

A total of three meetings were planned for the Technical Advisory Group. Two were held during the development of the work and one is to be scheduled at the close of the project (after this documentation is complete.) All meetings were held virtually using an online platform with meeting materials distributed prior to each, as appropriate.

Meeting #1 was held on May 4, 2018, with 17 of the 20 TAG members in attendance and one additional who provided feedback via email. Project team members participating in this initial meeting included Alex Karner and Julie Dunbar, along with FTA representatives Ken Cervenka, Jeff Roux, and Melissa Foreman. The agenda and goals for this first meeting were to:

1. Provide an overview of the project and its current status
2. Hear your reactions to:
    a. Our emphasis on user benefits as opposed to "pure" opportunities measures and
    b. Our "tiered" analysis approach
3. Discuss potential missing pieces

Alex provided a detailed presentation, which can be found here, and the group members asked questions and provided comment throughout his presentation. Table B-6 contains the meeting summary notes for meeting #1.

Table B-6 *Technical Advisory Group Meeting #1 Notes (May 2018 Meeting)*

TAG Member Comments/Questions	Staff Response
(Slide 10/11): The motivation for transit agencies is to attract riders and respond to the market needs, how will that be considered in this analysis, in addition to the demographics?	We are aware of this and will be sensitive to it as we can. We will try to include some discussion on this in the final product.
(Slide 7-10): Regarding the region wide analysis deficiencies, does it include participants in the 'Sustainable Communities Initiative" grant program?	A lot of the initial work was completed during my dissertation research when I was studying the Bay Area. The MPO there, the Metropolitan Transportation Commission was an SCI recipient.
The Sustainable Communities Program was a pilot program to analyze fair housing and spatial disparities in amenities, for underserved populations. He was just noting this information was out there in some regions and might be good for the project to consider.	The Affirmatively Furthering Fair Housing Rule was a great start towards linking transportation and housing and it's potentially something we can build upon.
Question about normative vs. positive distinction. Why do we need to include 'normative' discussions?	Normative is not 'why we should care' but more 'can we make a valid claim that something is fair'; i.e., to provide a sufficient level of service and try to identify ways to interpret results that are meaningful.
Suggests that we do not 'bake' normative goals into this technical analysis up front; he suggests it's a better approach to defer development of sufficiency standards until later. Perhaps consider development of tools that allow users to assess sufficiency if desired.	Agree, but just don't want to lose track of it. Will talk more to Josh about this offline.

Table B-6 (cont.) *Technical Advisory Group Meeting #1 Notes (May 2018 Meeting)*

TAG Member Comments/Questions	Staff Response
Given current situation of falling ridership and funding trends facing many transit agencies, he cautions us about incorporating equity/access analysis into service planning. Practitioners need tools they can use to accomplish other service planning goals and still say something about equity. There are a lot of measures available, but agencies need help in interpreting them within the context of other agency constraints.	This challenges the project scope, but we hope a service planner can take what we produce here and use it in their analysis; ensuring their overall service plan meets equity concerns.
Be cautious that the project tools don't end up being used to 'beat up' on transit agencies; focus on usability of measures, not ending up making planners uncomfortable without really saying what is equitable.	Hoping the project tools could be used to demonstrate, for example, if an agency is moving incrementally towards advancing equity.
Re: beta test sites, what about considering a city where the service is more polycentric, where areas of need might be more dispersed and not all CBD focused? Also a caution to be aware of major impediments to service (i.e., rivers, major roadway barriers, other choke points)	Both Houston and Phoenix address the polycentric suggestion.
Would like to see a larger, older transit system in the beta test sites.	We are aware that we are missing a 'legacy' system. The three primary test sites are locked in, but perhaps we could consider this request for the secondary test sites.
When looking at User Benefits, it would be good to stratify them in a more meaningful way, not just access to jobs downtown in the peak hour, but reflect access to jobs of all skill levels and at varying times of day. One caution though, the more variations we have, the less intuitive it may be to the end user. So we need to find the balance between details and usability, considering the broad based audience we hope to reach with this.	CAG had this same comment. He believes we will be able to address this in a meaningful way.
Will the analysis look at access to other services, not just jobs? The USDA food desert map and the "EJ Screen" tool developed by the Office of Environmental Justice might both provide useful resources.	Yes, we hope to include this as well. Existing tools can get at this for the most part, so our project may not focus on it but will try to provide some discussion as there is interest and it is relevant to the equity discussion for sure.
Three points, 1) regarding the notion of stratifying opportunities across different types; Existing tools may already have this covered. 2) User benefits can be conceptualized as reflecting a single person's accessibility – one person one opportunity [AK: Yes, but different data are required] 3) He supports the project goals regarding open source and open data, but on-board surveys do not match up well across agencies. Maybe the project can help move the industry towards open standards for ridership reporting and surveying, that would be an excellent contribution if possible. Mentions GTFS-ride (https://github.com/ODOT-PTS/GTFS-ride/wiki).	Would like to follow up with Anson offline to discuss Open Source/Standards in more detail

Table B-6 (cont.) *Technical Advisory Group Meeting #1 Notes (May 2018 Meeting)*

TAG Member Comments/Questions	Staff Response
He also likes the discussion of including reliability (mentioned a recent analysis by Farber) and to be able to use GTFS to get real time data.	Has found a lack of standardization in real time data across agencies, so this may be a problem.
Suggest we need to think clearly up-front regarding project objectives; is it that users don't have tools or don't know how to use the tools? Mentions a tension between wanting to include factors that have not previously been taken into account and simplicity. Caution about complexity and not wanting project to end up to challenging for end users to implement/interpret and use. Mentions user benefits likely requiring travel models. That all sounds good, but what is stopping the wide use of existing tools? How can we find help them find clarity and focus there; help to make existing tools useful and provide measured value?	The lit review showed that many tools do exist, but their usability is unclear (cost prohibitive, require consultants, etc.). We hope the project tools are more widely used, more meaningful and provide more actionable results. The key is 'actionable results'. Academic literature has very little on standardization. Regarding user benefits, we will not be estimating travel models in this project, but hope to use existing survey data for the analysis as illustrated in the slides. We hope our effort will show the benefit of better data (since all agencies do NOT have on board survey data); hope to build in the reliability and relevance factor with input from the Community Advisory Group as well.
From the intro, could we be looking beyond just transit? Perhaps considering the notion of transit desert, ridership versus productivity?	CAG mentioned this as well, commenting that for some areas we miss the true lack of access where bus is the ONLY option. We can look at transit only access but in the end it does not tell the whole story. How to incorporate cross-modal comparisons? Not sure how deeply we'll be able to get into it but it will be important to note.
Would you clarify the word 'multimodal' in the project title? Do you mean 'within public transportation' or do you mean park & ride, TNC, etc.? Regarding park-and-ride, how will tools measure accessibility? She agrees that the technique to evaluate this is not difficult, but the location and frequency of trips to park-and-ride might be a bigger equity issue.	TNC's are really outside of our scope. For this project, we are thinking about how people access transit, walk to transit, drive to transit etc. We could integrate transit and street networks to measure drive access; we will have drive access information for those agencies with On Board Survey data.

The second meeting of the Technical Advisory Group was held April 19, 2019, with 12 TAG members present. Project team representatives for this meeting included Alex Karner, Julie Dunbar, L. Alcorn, K. Levine and from FTA, Ken Cervenka and Melissa Foreman. The primary focus of this meeting was to review the white paper on proposed measures and gain TAG input. Dr. Karner presented an overview of the various measures via a presentation that can be found here. In addition, he explained how the scope of the work had broadened and presented a draft outline of the final report. TAG members offered a series of comments on the white paper and presentation slides as contained in Table B-7.

Table B-7 *Technical Advisory Group Meeting #2 Notes (April 2019 Meeting)*

TAG Member Comments/Questions	Staff Response
Slide: Two-dimensional graph of measures Cautioned about the overall intent of the project. He thinks we should ensure that the broader context of accessibility is clear. The services and investments many agencies are dealing with are not necessarily in sync with improved "access." For example, if a region is seeking to attract the next Amazon-type large employer, having equal access for all users is not in sync with this potential agency/regional goal. What is the threshold of disparity when something is "disparate" but accomplishes other goals the agency is pursuing? He thinks we need to acknowledge this up front and even direct users to some other literature and guidance for times when agency goals cause this sort of 'mismatch' in disparity. The 'base' for comparison has historically had better service for low-income riders (with historic concentrations in the core and service levels highest in the core), but how does gentrification now contribute to disparity in transit service when in fact it's not necessarily the "fault" of the transit system's level of access.	
Slide: Population count measure Want to call out the fact that HUD's Sustainable Communities Initiative in 2010-2015 helped 70+ regions doing exactly what the was just being discussed: do forward-looking regional planning with an eye on existing distributions of amenities, both geographical and demographic. A lot of that work went into the Affirmatively Furthering Far Housing rule, which mandates this sort of analysis for HUD grantees.	
Slide: Access to opportunities Another problem with access to opportunities: the cutoffs, even if "calibrated" lead to cliff effects that aren't proportional to the experienced benefits to the traveler. For example, a giant shopping center in Katy Texas that was previously 46 minutes away is now 45 minutes. This issue has been revealed in more than one project that I have worked on.	
Slide: Example of population buffer Another issue with the buffer access measure is that with the large variety of first/last mile options now available, there could be much greater "access" along a particular corridor than just from those people living or working within the buffer.	
Slide: Census Transportation Planning Package Clarification on a limitation of CTPP data, it does have used mode, but it is only the "usual mode" so it disproportionally drops infrequent modes which may provide critical flexibility to a household's transportation needs.	

Table B-7 (cont.) *Technical Advisory Group Meeting #2 Notes (April 2019 Meeting)*

TAG Member Comments/Questions	Staff Response
Slide: Logsums It is unfortunate that logsums are routinely coupled with travel demand models as you don't need a fully functioning TDM to use logsums in this way. You just need to assert a utility equation and as long as you have a transit network and available process for skimming the network, you can get at a logsum to measure changes in access reflected in the changes in network service. If you just assert a trade-off between time and cost, the logsum approach will still give you a 'richer' result than some of the other measures that end up with some fairly serious 'cliff' effects. Still challenging to explain what it means though.	
Asked for clarification on the ultimate product and audience? (Alex responded). Steve suggested again that the opening of the report should set the stage for the relevance of these measures to different applications (route versus system level improvements; varying agency goals; not appropriate in every situation and be sure to point that out).	
Are people using this analysis when considering high-capacity improvements, i.e., a new BRT line)?	Alex noted mostly they use the access to opportunities approach at this point, if anything, and noted the availability of Conveyal and Remix software to assist.
A specific comment concerning the point of cut-offs/cliff effects, he suggested we look at the SmartScale Initiative done in Virginia. He reported experience with states that are now starting to use a gravity model approach to avoid the cut offs. He asked if it was true that agencies are having a harder time getting revealed demand data?	Alex noted CTPP could be used to do some analysis and on-board surveys are not essential. The project hopes to show what else is available by having an on-board survey to assist agencies in determining if it's worth the cost and effort.
On page 7 of the white paper, 3rd paragraph from the bottom – the word "demand" should be "supply."	
How will the project address all the different answers an agency could get with the different tools (i.e., how easy might it be to game the system and pick the tool that gives you the desire-d outcome)?	Alex noted that the problem exists now, and in order to truly avoid that the project would have to make specific recommendations for use of the different measures which is too close to new guidance. We hope to come out with stronger normative recommendations of how the measures 'should be' used. Alex noted we could include 'edge cases' to show how the measures could lead to different results and the challenges and complexities of applying them.

Table B-7 (cont.) *Technical Advisory Group Meeting #2 Notes (April 2019 Meeting)*

The measures should be used for planning but not for compliance. Transit isn't a point source service, it's lines and networks. The project should include some discussion of the sensitivity of the tools to geometrics and barriers in a system such as environmental constraints (i.e., a river to cross). Agreed with SPolzin who suggested the idea that the two-dimensional "measures" graph could actually be three-dimensional with the 3rd dimension being network aware	
Suggests the acknowledgement of microtransit, micromobility, first/last mile services be broadened in how they impact the accessibility/connectivity measures discussion.	Alex responded that there is very limited data on the current trends for this access, but we should be able to add some Park and Ride discussion with at least acknowledgment of walk/drive access to stations.

Summary

Input from the TAG was logged carefully in the notes from each meeting. It was clear from discussions at both meetings that the issues related to data challenges and varying capabilities of transit agency staff to manipulate data at similar levels of expertise were concerning. Key points of note are:

- The analysis tools suggested in the project should be mindful of a transit agency's overall need to attract riders as well as serve varying travel markets; sometimes these two things work against each other. What is the threshold of disparity when something is "disparate" from an access standpoint, but accomplishes other goals the transit agency is pursuing? Be careful to better align equity considerations to planning, and what kinds of analyses are needed to understand the equity impacts for riders.
- Cautious approach to setting standards of "fairness" (i.e., normative versus positive standards) with a suggestion that users should be allowed to access project tools to assess sufficiency if desired. Predetermined standards of fairness could skew assessments inadvertently.
- TAG members expressed concern over the development of tools that could end up being used to "bash" public transit and encouraged the project team to develop measures that would be helpful to service planners as well; examples should show degrees of improvement not an absolute achievement of some set requirement for access to all.
- The beta test sites should include polycentric metropolitan areas and not just focus on one central business district and, if possible, include a larger, older transit system (legacy system).
- Encourage the team to consider more than just access to jobs in the peak period, but also access to other services.

- Caution about dissecting user benefits into layers by job skill level and time of day as the results may end up less and less intuitive to the average transit agency and/or audience.
- Supportive of the open-source nature of the proposed tools as well as the use of real-time GTFS data.
- Encouragement to provide better guidance for practitioners to make use of the tools that already exist and a caution that many of the existing tools aren't being widely used because of complexity, so be mindful as this project's tools become complex that the usability could be negatively impacted.
- Encourage team to maintain possibility to look beyond just transit and tap into the transit deserts that exist; look across modes for comparisons outside of transit.
- Note the use of the word "multimodal" in the title is somewhat misleading as it does not include TNCs or even drive along trips.
- Consider historical and current land use and housing policies and how they have been disjointed with transportation policies and the impacts that they have had in shaping disparities in the ability for people to have access to affordable transportation options. Caution that gentrification contributes to disparity in transit service but it's not because of transit system access; how to reflect these external characteristics to ensure accessibility measures are fair.
- Caution about cut-off points (or "cliffs") in buffer-type access analysis that might show something as worse off when it just happened to fall just outside the line in the new scenario. Also, the increased options for first/last mile access could be very different from one area of a region to another and result in disparity that isn't necessarily the agency's fault.
- Encourage the final report to address how easy it may be for a transit agency to get different answers using different tools and, therefore, game the system. Important to include examples that show how easily similar situations can be mis represented to encourage agencies not to game the analysis.

Acronyms and Abbreviations

ACS	American Community Survey
ADA	Americans with Disabilities Act
API	Application Programming Interface
AVL	Automatic Vehicle Locator
CAG	Community Advisory Group
CIG	Capital Investment Grant
CTPP	Census Transportation Planning Package
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GIS	Geographic Information System
GPS	Global Positioning System
GTFS	General Transit Feed Specification
H-GAC	Houston-Galveston Area Council
MBTA	Massachusetts Bay Transportation Authority
MPO	Metropolitan Planning Organization
NCHRP	National Cooperative Highway Research Program
OD	Origin-Destination
OTP	OpenTripPlanner
RTPO	Regional Transportation Planning Organization
SR	System Reimagining
STOPS	Simplified Trips-on-Project Software
TAG	Technical Advisory Group
TAZ	Transportation Analysis Zone
TBEST	Transit Boardings Estimation and Simulation Tool
TNC	Transportation Network Company
TPOM	Transportation Partnership on Mobility
USDOT	United States Department of Transportation

References

1. Taylor, B. D., and E. A. Morris. “Public Transportation Objectives and Rider Demographics: Are Transit’s Priorities Poor Public Policy?” *Transportation* 42, no. 2 (2015): 347–67. https://doi.org/10.1007/s11116-014-9547-0.
2. Grengs, J. “The Abandoned Social Goals of Public Transit in the Neoliberal City of the USA.” *City* 9, no. 1 (2005): 51–66. https://doi.org/10.1080/13604810500050161.
3. Karner, A., and A. Golub. “Assessing the Equity Impacts of a Transportation Improvement Program.” In *Measuring Transport Equity* (K. Lucas, K. Martens, F. Di Ciommo, and A. Dupont-Kieffer, eds.). Amsterdam: Elsevier, 2019.
4. Karner, A., and A. Golub. “Comparison of Two Common Approaches to Public Transit Service Equity Evaluation.” *Transportation Research Record: Journal of the Transportation Research Board* 2531 (2015): 170–79. https://doi.org/10.3141/2531-20.
5. Karner, A. “Planning for Transportation Equity in Small Regions: Towards Meaningful Performance Assessment.” *Transport Policy* 52 (2016): 46–54. https://doi.org/10.1016/j.tranpol.2016.07.004.
6. Karner, A., and D. Niemeier. “Civil Rights Guidance and Equity Analysis Methods for Regional Transportation Plans: A Critical Review of Literature and Practice.” *Journal of Transport Geography* 33 (2013): 126–34. https://doi.org/10.1016/j.jtrangeo.2013.09.017.
7. Hansen, W. G. “How Accessibility Shapes Land Use.” *Journal of the American Institute of Planners* 25, no. 2 (1959): 73–76.
8. Wachs, M., and T. G. Kumagai. “Physical Accessibility as a Social Indicator.” *Socio-Economic Planning Sciences* 7, no. 5 (1973): 437–56. https://doi.org/10.1016/0038-0121(73)90041-4.
9. Pereira, R. H. M., T. Schwanen, and D. Banister. “Distributive Justice and Equity in Transportation.” *Transport Reviews* 37, no. 2 (2017): 170–91. https://doi.org/10.1080/01441647.2016.1257660.
10. Martens, K. “Justice in Transport as Justice in Accessibility: Applying Walzer’s ‘Spheres of Justice’ to the Transport Sector.” *Transportation* 39, no. 6 (2012): 1035–53. http://link.springer.com/journal/volumesAndIssues/11116.
11. Martens, K., A. Golub, and G. Robinson. “A Justice-Theoretic Approach to the Distribution of Transportation Benefits: Implications for Transportation Planning Practice in the United States.” *Transportation Research Part A: Policy and Practice* 46, no. 4 (2012): 684–95. https://doi.org/10.1016/j.tra.2012.01.004.
12. Martens, K. *Transport Justice: Designing Fair Transportation Systems*. New York: Routledge, 2016.
13. Lucas, K. “Transport and Social Exclusion: Where Are We Now?” *Transport Policy* 20 (2012): 105–13. https://doi.org/10.1016/j.tranpol.2012.01.013.
14. Johnson, D., M. Ercolani, and P. Mackie. “Econometric Analysis of the Link between Public Transport Accessibility and Employment.” *Transport Policy* 60 (2017): 1–9. https://doi.org/10.1016/j.tranpol.2017.08.001.
15. Handy, S., and D. Niemeier. “Measuring Accessibility: An Exploration of Issues and Alternatives.” *Environment and Planning A* 29, no. 7 (1997): 1175–94. https://doi.org/10.1068/a291175.

16. Geurs, K. T., and B. van Wee. "Accessibility Evaluation of Land-Use and Transport Strategies: Review and Research Directions." *Journal of Transport Geography* 12, no. 2 (2004): 127–40. https://doi.org/10.1016/j.jtrangeo.2003.10.005.
17. Kwan, M.-P. "Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-Based Framework." *Geographical Analysis* 30, no. 3 (1998): 191–216. https://doi.org/10.1111/j.1538-4632.1998.tb00396.x.
18. Páez, A., D. M. Scott, and C. Morency. "Measuring Accessibility: Positive and Normative Implementations of Various Accessibility Indicators." *Journal of Transport Geography* 25 (2012): 141–53. https://doi.org/10.1016/j.jtrangeo.2012.03.016.
19. Lei, T. L., and R. L. Church. "Mapping Transit-based Access: Integrating GIS, Routes and Schedules." *International Journal of Geographical Information Science* 24, no. 2 (2010): 283–304. https://doi.org/10.1080/13658810902835404.
20. Boisjoly, G., and A. M. El-Geneidy. "The Insider: A Planners' Perspective on Accessibility." *Journal of Transport Geography* 64 (2017): 33–43. https://doi.org/10.1016/j.jtrangeo.2017.08.006.
21. Boisjoly, G., and A. M. El-Geneidy. "How to Get There? A Critical Assessment of Accessibility Objectives and Indicators in Metropolitan Transportation Plans." *Transport Policy* 55 (2017): 38–50. https://doi.org/10.1016/j.tranpol.2016.12.011.
22. Papa, E., C. Silva, M. te Brömmelstroet, and A. Hull. "Accessibility Instruments for Planning Practice: A Review of European Experiences." *Journal of Transport and Land Use* 9, no. 3 (2016): 57–75.
23. Silva, C., L. Bertolini, M. te Brömmelstroet, D. Milakis, and E. Papa. "Accessibility Instruments in Planning Practice: Bridging the Implementation Gap." *Transport Policy* 53 (2017): 135–45. https://doi.org/10.1016/j.tranpol.2016.09.006.
24. Stewart, A. F. "Mapping Transit Accessibility: Possibilities for Public Participation." *Transportation Research Part A: Policy and Practice* 104, Supplement C (2017): 150–66. https://doi.org/10.1016/j.tra.2017.03.015.
25. Stewart, A. F., and P. C. Zegras. "CoAXs: A Collaborative Accessibility-Based Stakeholder Engagement System for Communicating Transport Impacts." *Research in Transportation Economics* 59 (2016): 423–33. https://doi.org/10.1016/j.retrec.2016.07.016.
26. Handy, S. "Regional Transportation Planning in the US: An Examination of Changes in Technical Aspects of the Planning Process in Response to Changing Goals." *Transport Policy* 15, no. 2 (2008): 113–26.
27. Farber, S., M. Z. Morang, and M. J. Widener. "Temporal Variability in Transit-Based Accessibility to Supermarkets." *Applied Geography* 53 (2014): 149–59. https://doi.org/10.1016/j.apgeog.2014.06.012.
28. Wong, J. "Leveraging the General Transit Feed Specification for Efficient Transit Analysis." *Transportation Research Record: Journal of the Transportation Research Board* 2338 (2013): 11–19. https://doi.org/10.3141/2338-02.
29. Fayyaz, S. K., X. C. Liu, and G. Zhang. "An Efficient General Transit Feed Specification (GTFS) Enabled Algorithm for Dynamic Transit Accessibility Analysis." *PLOS ONE* 12, no. 10 (2017): e0185333. https://doi.org/10.1371/journal.pone.0185333.

30. Karner, A. “Assessing Public Transit Service Equity Using Route-Level Accessibility Measures and Public Data.” *Journal of Transport Geography* 67 (2018): 24–32. https://doi.org/10.1016/j.jtrangeo.2018.01.005.
31. Karner, A., A. Golub, and C. Chavis. *Understanding Regional Disparities in Public Transit Performance Using Realtime Transit Data*. College Park, MD: University of Maryland National Transportation Center, 2016.
32. El-Geneidy, A. M., J. Horning, and K. J. Krizek. “Analyzing Transit Service Reliability Using Detailed Data from Automatic Vehicular Locator Systems.” *Journal of Advanced Transportation* 45, no. 1 (2011): 66–79. https://doi.org/10.1002/atr.134.
33. Wang, F., and Y. Xu. “Estimating O–D Travel Time Matrix by Google Maps API: Implementation, Advantages, and Implications.” *Annals of GIS* 17, no. 4 (2011): 199–209. https://doi.org/10.1080/19475683.2011.625977.
34. Sanchez, T., R. Stolz, and J. S. Ma. *Moving to Equity: Addressing Inequitable Effects of Transportation Policies on Minorities*. Cambridge, MA: The Civil Rights Project at Harvard University, 2003.
35. Duthie, J., K. Cervenka, and S. Waller. “Environmental Justice Analysis: Challenges for Metropolitan Transportation Planning.” *Transportation Research Record: Journal of the Transportation Research Board* 2013 (2007): 8–12. https://doi.org/10.3141/2013-02.
36. Karner, A., and R. A. Marcantonio. “Achieving Transportation Equity: Meaningful Public Involvement to Meet the Needs of Underserved Communities.” *Public Works Management & Policy* 23, no. 2 (2018): 105–26. https://doi.org/10.1177/1087724X17738792.
37. Marcantonio, R., A. Golub, A. Karner, and L. N. Dyble. “Confronting Inequality in Metropolitan Regions: Realizing the Promise of Civil Rights and Environmental Justice in Metropolitan Transportation Planning.” *Fordham Urban Law Journal* 44 (2017): 1017–77.
38. Federal Highway Administration and Federal Transit Administration. *The Transportation Planning Process Briefing Book*. Publication FHWA-HEP-18-005. Washington, DC: Transportation Planning Capacity Building Program, 2018.
39. Karner, A., A. Golub, K. Martens, and G. Robinson. “Transportation and Environmental Justice: History and Emerging Practice.” In *The Routledge Handbook of Environmental Justice* (R. Holifield, J. Chakraborty, and G. Walker, eds.), 400–11. New York: Routledge, Taylor & Francis Group, 2018.
40. Bullard, R. D., and G. S. Johnson, eds. *Just Transportation: Dismantling Race & Class Barriers to Mobility*. Gabriola Island, BC: New Society Publishers, 1997.
41. Bullard, R. D., G. S. Johnson, and A. O. Torres, eds. *Highway Robbery: Transportation Racism & New Routes to Equity*. Cambridge, MA: South End Press, 2004.
42. Cole, L. W., and S. R. Foster. *From the Ground Up: Environmental Racism and the Rise of the Environmental Justice Movement*. New York: New York University Press, 2001.
43. McGurty, E. *Transforming Environmentalism: Warren County, PCBs, And the Origins of Environmental Justice*. New Brunswick, NJ: Rutgers University Press, 2007.
44. Clinton, W. J. Executive Order 12898: Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations. *Federal Register* 59, no. 32 (1994): 7629–33.

45. Clinton, W. J. Executive Order 13166: Improving Access to Services for Persons With Limited English Proficiency. *Federal Register* 65, no. 159 (2000): 50121–22.

46. Trujillo, J. M. Policy Guidance Concerning Recipients' Responsibilities to Limited English Proficient (LEP) Persons. *Federal Register* 70, no. 239 (2005): 74087–89.

47. Bush, G. W. Executive Order 13330: Human Service Transportation Coordination. *Federal Register* 69, no. 38 (2004): 9185–87.

48. Federal Transit Administration. *Circular FTA C 4702.1B: Title VI Requirements and Guidelines for Federal Transit Administration Recipients*. Washington, DC: US Department of Transportation, 2012.

49. Federal Transit Administration. *Circular FTA C 4703.1: Environmental Justice Policy Guidance for ederal Transit Administration Recipients*. US Department of Transportation, 2012.

50. Federal Highway Administration. *FHWA Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (Order 6640.23A).* Washington, DC: US Department of Transportation, 2012.

51. CDM Smith and Corey, Canapary & Galanis Research. *BART-to-Oakland International Airport Title VI Equity Analysis,* 2014.

52. Aimen, D., and A. Morris. *NCHRP Report 710: Practical Approaches for Involving Traditionally Underserved Populations in Transportation Decision Making*, Publication 710. Washington, DC: Transportation Research Board, 2012.

53. Weiss, R. S. *Learning From Strangers: The Art and Method of Qualitative Interview Studies*. New York: Free Press, 1995.

54. Marcantonio, R., and A. Karner. "Disadvantaged Communities Teach Regional Planners a Lesson in Equitable and Sustainable Development." *Poverty & Race* 23, no. 1 (2014): 5–12.

55. Jahangiri, A. "Reforming the Capital Metro Board Citizen Advisory Committees." *Farm & City* (May 10, 2018).

56. London, J. K., J. Sze, and R. S. Liévanos. "Problems, Promise, Progress, and Perils: Critical Reflections on Environmental Justice Policy Implementation in California." *UCLA Journal of Environmental Law and Policy* 26, no. 2 (2008): 255–89.

57. London, J., A. Karner, J. Sze, D. Rowan, G. Gambirazzio, and D. Niemeier. "Racing Climate Change: Collaboration and Conflict in California's Global Climate Change Policy Arena." *Global Environmental Change* 23, no. 4 (2013): 791–99. https://doi.org/10.1016/j.gloenvcha.2013.03.001.

58. TriMet. *2016 Title VI Program Update*. TriMet, 2016.

59. TriMet Staff. Transit Equity Advisory Committee, February 26, 2019.

60. TriMet Staff. TriMet Interview, August 15, 2019.

61. TriMet. Transit Equity Advisory Committee Minutes. https://trimet.org/meetings/teac/pdfs/2018-06-21/minutes-6-21-18.pdf.

62. CapMetro. "Community Involvement." *CapMetro*. https://capmetro.org/getinvolved/#!

63. CapMetro. *Access Advisory Committee Action Report*, 2014.

64. Sound Transit. Citizens Accessibility Advisory Committee. https://www.soundtransit.org/get-to-know-us/panels-committees/citizens-accessibility-advisory-committee.

65. City of Seattle. Seattle Pedestrian Advisory Board. https://www.seattle.gov/seattle-pedestrian-advisory-board.
66. Seattle Department of Transportation. *City of Seattle Pedestrian Master Plan*, 2017.
67. Seattle Department of Transportation. *2018–2022 Implementation Plan and Progress Report*, 2017.
68. Ped Advisory Board. @SeattlePed Meeting, January 10, 2018.
69. Customer Satisfaction Advisory Committee. CSAC Resolutions. https://www.capmetro.org/uploadedFiles/Capmetroorg/Public_Involvement/Customer_Service_Advisory_Committee/2014-csac-resolutions-and-status.pdf.
70. Customer Satisfaction Advisory Committee. *December 2018 Minutes*. CapMetro, 2018.
71. MBTA. MBTA Rider Oversight Committee: About. *MBTA Rider Oversight Committee*. https://mbtaroc.org/about/.
72. Hamwey, S. Rail Vision: Transforming the T. https://www.mbta.com/projects/rail-vision.
73. Sound Transit. *System Expansion Implementation Plan June 2018.pdf*, 2018.
74. Sound Transit. "Sound Transit Board Identifies Alternatives for Environmental Study for West Seattle and Ballard Link Extensions." https://www.soundtransit.org/get-to-know-us/news-events/news-releases/sound-transit-board-identifies-alternatives-environmental.
75. Sanchez, T. *An Inherent Bias? Geographic and Racial-Ethnic Patterns of Metropolitan Planning Organization Boards*. Washington, DC: Brookings Institution Metropolitan Policy Program, 2006.
76. Sanchez, T. W., and J. Wolf. "Environmental Justice and Transportation Equity: A Review of MPOs." In *Growing Smarter: Achieving Livable Communities, Environmental Justice, and Regional Equity* (R. D. Bullard, ed.). Cambridge, MA: MIT Press, 2007.
77. York, T. "TriMet's Low-Income Fare Program on Track to Exceed First Year Expectations." *TriMet News*, January 29, 2019.
78. MBTA Staff. MBTA Interview, July 1, 2019.
79. Rabbittransit Director. Rabbittransit Interview, April 11, 2019.
80. Reedy, J. "Eat. Play. Breathe. Rethinking Public Transit Space for Better Health." *Passenger Transport*. https://perma.cc/DS4E-3SA8.
81. LINK Houston Staff. LINK Houston Interview, April 30, 2019.
82. MBTA. *MBTA Title VI Report*. Massachusetts Bay Transportation Authority (2017): 294.
83. MassDOT Staff. MassDOT Interview, June 10, 2019.
84. MassDOT. Engage.
85. CapMetro Staff. CapMetro Interview, August 12, 2019.
86. Travis County. *Travis County Transportation Blueprint*, 2019.
87. McAshan, B. "Houston Disability Activist Lex Frieden." *TMC News*, 2018.
88. Begley, D. "Metro Investing in Sidewalks so Elderly, Disabled Can Get to Bus Stops." *Houston Chronicle*. https://www.houstonchronicle.com/news/transportation/article/Metro-investing-in-sidewalks-so-elderly-disabled-13647008.php.
89. TransitCenter. *Alliances That Get Results*, 2017.

90. Thornton, R. “Capital Metro Votes Kids Ride Free, Forever.” *Austin Monitor*. https://www.austinmonitor.com/stories/2018/12/capital-metro-votes-kids-ride-free-forever/.

91. Denney, A. “No Emissions Here: Capital Metro Tests out Electric Buses in Austin.” *Community Impact Newspaper*. https://communityimpact.com/austin/top-stories/2018/08/14/no-emissions-here-capital-metro-tests-out-electric-buses-in-austin/.

92. Niezgoda, A. “Protesters Call for MBTA to Offer Reduced-Fare Option for Low-Income Riders.” *NBC10 Boston*. http://www.nbcboston.com/news/local/Protesters-Call-for-MBTA-to-Offer-Reduced-Fare-Option-for-Low-Income-Riders-513064281.html.

93. LINK Houston. *Equity in Transit: 2020 Report*. Houston, TX (2018): 13.

94. LINK Houston. “LINK Houston, BikeHouston, and Community Members to Address City Council on Safer Streets Initiative.” *LinkHouston* (March 25, 2019).

95. Mikati, M. “Mayor Turner Announces Pedestrian Safety Measures in Wake of Fatal Heights Crash.” *Houston Chronicle*. https://www.houstonchronicle.com/news/houston-texas/houston/article/Mayor-Turner-announces-pedestrian-safety-measures-13761090.php.

96. LINK Houston. “News from LINK Houston” (April 15, 2019).

97. TransitMatters. “Initiatives Overview.” *TransitMatters*. http://transitmatters.org/initiatives.

98. Ebuna, M., and J. Fairchild. “TransitMatters Outlines Faster Forward Initiative.” *CommonWealth Magazine* (February 2, 2017).

99. LivableStreets Alliance. “Better Buses.” https://www.livablestreets.info/better_buses.

100. Miller, S. “When Street Parking Becomes a Pop-Up Bus Lane.” *CityLab*. https://www.citylab.com/commute/2017/02/when-street-parking-becomes-a-pop-up-bus-lane/517404/.

101. STREETFILMS. “A Street Is a Terrible Thing to Waste: Boston’s Newest Bus Lane.” https://vimeo.com/273912379.

102. HGAC. *2040 Regional Transportation Plan, Appendix B: Environmental Justice Analysis*. Houston, TX: Houston-Galveston Area Council, 2016.

103. Seattle Department of Transportation. *SDOT Sidewalk Condition Assessment Report*, 2018.

104. Seattle Department of Transportation, and Sound Transit GIS. “Seattle Accessible Route Planner.” https://seattlecitygis.maps.arcgis.com/apps/webappviewer/index.html?id=86cb6824307c4d63b8e180ebcff58ce2.

105. Shaheen, S., and N. Chan. “Mobility and the Sharing Economy: Potential to Facilitate the First- and Last-Mile Public Transit Connections.” *Built Environment* 42, no. 4 (2016): 573–88. https://doi.org/10.2148/benv.42.4.573.

106. Shaheen, S., and A. Cohen. “Chapter 3 - Mobility on Demand (MOD) and Mobility as a Service (MaaS): Early Understanding of Shared Mobility Impacts and Public Transit Partnerships.” In *Demand for Emerging Transportation Systems* (C. Antoniou, D. Efthymiou, and E. Chaniotakis, eds.), 37–59. Elsevier, 2019.

107. FHWA and FTA. *Travel Behavior: Shared Mobility and Transportation Equity*. Washington, DC: US Department of Transportation, Federal Highway Administration, 2017.

108. Walker, J. *Human Transit: How Clearer Thinking about Public Transit Can Enrich Our Communities and Our Lives*. Washington, DC: Island Press, 2012.

109. CapMetro. August 2019 Service Changes. https://capmetro.org/august2019/#!

110. CapMetro. Pickup Service Areas, 2019.

111. Houston METRO. Public Engagement Department. Houston METRO Interview, April 16, 2019.

112. Houston METRO. *METRO Highlights*, 2018.

113. CUMTD Staff. CUMTD Interview, April 12, 2019.

114. CapMetro. Pickup FAQs. https://capmetro.org/pickup-faq/#!

115. Ashley, A. J., C. G. Loh, K. Bubb, and L. Durham. "Diversity, Equity, and Inclusion Practices in Arts and Cultural Planning." *Journal of Urban Affairs* (2021): 1–21. https://doi.org/10.1080/07352166.2020.1834405.

116. Toole, J., T. L. Butler, and J. Chrzan. :How to Place Equity at the Center of Our Work." *ITE Journal* 90, no. 2 (2020): 37–41.

117. MBTA. "Bus Cost-Efficiency Tool." *Data Blog*. http://www.mbtabackontrack.com/blog/70-bus-cost-efficiency-tool.

118. York, T. "TriMet's Low-Income Fare Program on Track to Exceed First Year Expectations." *TriMet News* (January 29, 2019).

119. Dalvi, M. Q., and K. M. Martin. "The Measurement of Accessibility: Some Preliminary Results." *Transportation* 5, no. 1 (1976): 17–42. https://doi.org/10.1007/BF00165245.

120. Levinson, D., W. Marshall, and K. Axhausen. *Elements of Access*. Network Design Lab, 2017.

121. Currie, G. "Quantifying Spatial Gaps in Public Transport Supply Based on Social Needs." *Journal of Transport Geography* 18, no. 1 (2010): 31–41. https://doi.org/10.1016/j.jtrangeo.2008.12.002.

122. Delbosc, A., and G. Currie. "Using Lorenz Curves to Assess Public Transport Equity." *Journal of Transport Geography* 19, no. 6 (2011): 1252–59. https://doi.org/10.1016/j.jtrangeo.2011.02.008.

123. Frappier, A., C. Morency, and M. Trépanier. "Measuring the Quality and Diversity of Transit Alternatives." *Transport Policy* 61 (2018): 51–59. https://doi.org/10.1016/j.tranpol.2017.10.007.

124. Wu, B. M., and J. P. Hine. "A PTAL Approach to Measuring Changes in Bus Service Accessibility." *Transport Policy* 10, no. 4 (2003): 307–320. https://doi.org/10.1016/S0967-070X(03)00053-2.

125. Golub, A., G. Robinson, and B. Nee. "Making Accessibility Analyses Accessible: A Tool to Facilitate the Public Review of the Effects of Regional Transportation Plans on Accessibility." *Journal of Transport and Land Use* 6, no. 3 (2013): 17–28.

126. Golub, A., and K. Martens. "Using Principles of Justice to Assess the Modal Equity of Regional Transportation Plans." *Journal of Transport Geography* 41 (2014): 10–20. https://doi.org/10.1016/j.jtrangeo.2014.07.014.

127. Levinson, D. *Access Across America*. Minneapolis, MN: Department of Civil Engineering, University of Minnesota, 2013.

128. Allen, J., and S. Farber. "Sizing up Transport Poverty: A National Scale Accounting of Low-Income Households Suffering from Inaccessibility in Canada, and What to Do about It." *Transport Policy* 74 (2019): 214–23. https://doi.org/10.1016/j.tranpol.2018.11.018.

129. Hu, L. “Job Accessibility of the Poor in Los Angeles.” *Journal of the American Planning Association* 81, no. 1 (2015): 30–45. https://doi.org/10.1080/01944363.2015.1042014.

130. Kawabata, M., and Q. Shen. “Commuting Inequality between Cars and Public Transit: The Case of the San Francisco Bay Area, 1990-2000.” *Urban Studies* 44, no. 9 (2007): 1759–80. https://doi.org/10.1080/00420980701426616.

131. Merlin, L. A., and L. Hu. “Does Competition Matter in Measures of Job Accessibility? Explaining Employment in Los Angeles.” *Journal of Transport Geography* 64 (2017): 77–88. https://doi.org/10.1016/j.jtrangeo.2017.08.009.

132. Shen, Q. “A Spatial Analysis of Job Openings and Access in a U.S. Metropolitan Area.” *Journal of the American Planning Association* 67, no. 1 (2001): 53–68. https://doi.org/10.1080/01944360108976355.

133. Shen, Q. “Location Characteristics of Inner-City Neighborhoods and Employment Accessibility of Low-Wage Workers.” *Environment and Planning B: Planning and Design* 25, no. 3 (1998): 345–65.

134. Ben-Akiva, M., and S. R. Lerman. *Discrete Choice Analysis: Theory and Application to Travel Demand*. Cambridge, MA: MIT Press, 1985.

135. Los Angeles County Metropolitan Transportation Authority. *Cumulative Service Equity Analysis Narrative of Methodology and Results*. Los Angeles, CA, 2013.

136. Rowangould, D., A. Karner, and J. London. “Identifying Environmental Justice Communities for Transportation Analysis.” *Transportation Research Part A: Policy and Practice* 88 (2016): 151–62.

137. Pereira, R. H. M., M. Saraiva, D. Herszenhut, C. K. V. Braga, and M. W. Conway. “R5r: Rapid Realistic Routing on Multimodal Transport Networks with R5 in R.” *Findings* (2021). https://doi.org/10.32866/001c.21262.

138. Karner, A., and J. London. “Rural Communities and Transportation Equity in California’s San Joaquin Valley.” *Transportation Research Record,* 2452 (2014): 90–97. https://doi.org/10.3141/2452-11.

139. Páez, A., R. G. Mercado, S. Farber, C. Morency, and M. Roorda. “Accessibility to Health Care Facilities in Montreal Island: An Application of Relative Accessibility Indicators from the Perspective of Senior and Non-Senior Residents.” *International Journal of Health Geographics* 9 (2010): 52. https://doi.org/10.1186/1476-072X-9-52.

140. Páez, A., R. G. Mercado, S. Farber, C. Morency, and M. Roorda. “Relative Accessibility Deprivation Indicators for Urban Settings: Definitions and Application to Food Deserts in Montreal.” *Urban Studies* 47, no. 7 (2010): 1415–38. https://doi.org/10.1177/0042098009353626.

141. Washington Metropolitan Area Transit Authority, Metropolitan Atlanta Rapid Transit Authority, Metro Transit, Federal Transit Administration, U.S. Department of Transportation, and Volpe National Transportation Systems Center. “Effective Practices in Title VI Transit Equity Analysis for Major Transit Service and Fare Changes.” Presented at the American Public Transportation Association Bus & Paratransit Conference, Memphis, TN, 2011.

142. Battiston, L. “Public Invited To Help Shape the Future of the MBTA Commuter Rail.” *MBTA*. https://www.mbta.com/news/2019-02-06/public-invited-help-shape-the-future-the-mbta-commuter-rail.

143. Resource Systems Group. *User Guide: Simplified Trips-on-Project Software, Version 2.50*. Arlington, VA, 2019.

144. Niemeier, D. A. "Accessibility: An Evaluation Using Consumer Welfare." *Transportation* 24, no. 4 (1997): 377–96. https://doi.org/10.1023/A:1004914803019.

145. Houston METRO. *Reimagined 5-Year Transit Service Plan (Draft)*. Houston, TX: Metropolitan Transit Authority of Harris County, Texas, 2014.

146. Houston METRO. *System Reimagining Draft 5-Year Transit Service Plan: Presentation to Houston City Council Committee Transportation, Technology, & Infrastructure*. Houston, TX, 2014.

147. Hess, D. B., and T. M. Almeida. "Impact of Proximity to Light Rail Rapid Transit on Station-Area Property Values in Buffalo, New York." *Urban Studies* 44, no. 5–6 (2007): 1041–68. https://doi.org/10.1080/00420980701256005.

148. Seo, K., A. Golub, and M. Kuby. "Combined Impacts of Highways and Light Rail Transit on Residential Property Values: A Spatial Hedonic Price Model for Phoenix, Arizona." *Journal of Transport Geography* 41 (2014): 53–62. https://doi.org/10.1016/j.jtrangeo.2014.08.003.

149. Stokenberga, A. "Does Bus Rapid Transit Influence Urban Land Development and Property Values: A Review of the Literature." *Transport Reviews* 34, no. 3 (2014): 276–96. https://doi.org/10.1080/01441647.2014.902404.

150. Golub, A., L. Brown, M. Grant, C. Ryerson, M. Gray, S. Lonsdale, and M. Levy. *Addressing Changing Demographics in Environmental Justice Analysis, State of Practice*. Washington, DC: Federal Highway Administration, 2019.

151. Manaugh, K., and A. El-Geneidy. "Who Benefits from New Transportation Infrastructure? Using Accessibility Measures to Evaluate Social Equity in Public Transport Provision." In *Accessibility Analysis and Transport Planning* (K. T. Geurs, K. K. Krizek, and A. Reggiani, eds.). Cheltenham, UK: Edward Elgar Publishing, 2012.

152. Martens, K., and A. Golub. "A Fair Distribution of Accessibility: Interpreting Civil Rights Regulations for Regional Transportation Plans." *Journal of Planning Education and Research* (2018): 0739456X1879101. https://doi.org/10.1177/0739456X18791014.

153. Walker, J. "To Predict with Confidence, Plan for Freedom." *Journal of Public Transportation* 21, no. 1 (2018): 119–27. https://doi.org/10.5038/2375-0901.21.1.12.

154. Garrett, M., and B. D. Taylor. "Reconsidering Social Equity in Public Transit." *Berkeley Planning Journal* 13 (1999): 6–27.

155. Brown, A. E. "Car-Less or Car-Free? Socioeconomic and Mobility Differences among Zero-Car Households." *Transport Policy* 60 (2017): 152–59. https://doi.org/10.1016/j.tranpol.2017.09.016.

156. Lovejoy, K. *Mobility Fulfillment among Low-Car Households: Implications for Reducing Auto Dependence in the United States*. PhD Dissertation. University of California, Davis, 2012.

157. Nordbakke, S., and T. Schwanen. "Transport, Unmet Activity Needs and Wellbeing in Later Life: Exploring the Links." *Transportation 42*, no. 6 (2015): 1129–51. https://doi.org/10.1007/s11116-014-9558-x.

158. Schaller, B. *TCRP Synthesis 63: On-Board and Intercept Transit Survey Techniques*. Washington, DC: Transit Cooperative Research Program, 2005.

159. US Department of Transportation and Federal Transit Administration. *Final Interim Policy Guidance Federal Transit Administration Capital Investment Grant Program*. Washington, DC, 2016.

160. Calabrese, F., G. D. Lorenzo, L. Liu, and C. Ratti. "Estimating Origin-Destination Flows Using Mobile Phone Location Data." *IEEE Pervasive Computing* 10, no. 4 (2011): 36–44. https://doi.org/10.1109/MPRV.2011.41.

161. Widhalm, P., Y. Yang, M. Ulm, S. Athavale, and M. C. González. "Discovering Urban Activity Patterns in Cell Phone Data." *Transportation* 42, no. 4 (2015): 597–623. https://doi.org/10.1007/s11116-015-9598-x.

162. Bunel, M., and E. Tovar. "Key Issues in Local Job Accessibility Measurement: Different Models Mean Different Results." *Urban Studies* 51, no. 6 (2014): 1322–38. https://doi.org/10.1177/0042098013495573.

163. Bezyak, J. L., S. A. Sabella, and R. H. Gattis. "Public Transportation: An Investigation of Barriers for People With Disabilities." *Journal of Disability Policy Studies* 28, no. 1 (2017): 52–60. https://doi.org/10.1177/1044207317702070.

164. Lubitow, A., J. Rainer, and S. Bassett. "Exclusion and Vulnerability on Public Transit: Experiences of Transit Dependent Riders in Portland, Oregon." *Mobilities* 12, no. 6 (2017): 924–37.

165. Levine, K., and A. Karner. "Measuring Access to Public Transit for People with Disabilities Using Detailed Sidewalk Data." Presented at the 99th Transportation Research Board Annual Meeting, Washington, DC, 2020.

166. Wolf, J., R. Guensler, and W. Bachman. "Elimination of the Travel Diary: Experiment to Derive Trip Purpose from Global Positioning System Travel Data." *Transportation Research Record: Journal of the Transportation Research Board* 1768 (2001): 125–34. https://doi.org/10.3141/1768-15.

167. Pelletier, M.-P., M. Trépanier, and C. Morency. "Smart Card Data Use in Public Transit: A Literature Review." *Transportation Research Part C: Emerging Technologies* 19, no. 4 (2011): 557–68. https://doi.org/10.1016/j.trc.2010.12.003.

168. Murakami, E., and D. P. Wagner. "Can Using Global Positioning System (GPS) Improve Trip Reporting?" *Transportation Research Part C: Emerging Technologies* 7, no. 2 (1999): 149–65. https://doi.org/10.1016/S0968-090X(99)00017-0.

169. McNally, M. G. "The Four-Step Model." In *Handbook of Transport Modelling* (D. A. Hensher and K. J. Button, eds.), 35–53. Emerald Group Publishing Limited, 2007.

170. McNally, M. G., and C. Rindt. "The Activity-Based Approach." In *Handbook of Transport Modelling*, 2nd Edition (D. A. Hensher and K. J. Button, eds.). Emerald Group Publishing Limited, 2007.

171. Algers, S., J. Eliasson, and L.-G. Mattsson. "Is It Time to Use Activity-Based Urban Transport Models? A Discussion of Planning Needs and Modelling Possibilities." *The Annals of Regional Science* 39, no. 4 (2005): 767–89.

172. Axhausen, K. W., and T. Garling. "Activity-Based Approaches to Travel Analysis: Conceptual Frameworks, Models, and Research Problems." *Transport Reviews* 12, no. 4 (1992): 323–41.

173. Abowd, J. M., J. Haltiwanger, and J. Lane. "Integrated Longitudinal Employer-Employee Data for the United States." *The American Economic Review* 94, no. 2 (2004): 224–29. https://doi.org/10.2307/3592887.

174. Fayyaz, S. K., X. C. Liu, and R. J. Porter. "Dynamic Transit Accessibility and Transit Gap Causality Analysis." *Journal of Transport Geography* 59 (2017): 27–39. https://doi.org/10.1016/j.jtrangeo.2017.01.006.

175. Fransen, K., T. Neutens, S. Farber, P. De Maeyer, G. Deruyter, and F. Witlox. “Identifying Public Transport Gaps Using Time-Dependent Accessibility Levels.” *Journal of Transport Geography* 48 (2015): 176–87. https://doi.org/10.1016/j.jtrangeo.2015.09.008.

176. McHugh, B. “Pioneering Open Data Standards: The GTFS Story.” In *Beyond Transparency: Open Data and the Future of Civic Innovation* (B. Goldstein and L. Dyson, eds.), 125–35. San Francisco: Code for America Press.

177. Farber, S., and L. Fu. “Dynamic Public Transit Accessibility Using Travel Time Cubes: Comparing the Effects of Infrastructure (Dis)Investments over Time.” *Computers, Environment and Urban Systems* 62 (2017): 30–40. https://doi.org/10.1016/j.compenvurbsys.2016.10.005.

178. Morang, M. Z. “Add GTFS to a Network Dataset.” Last updated November 11, 2021. https://www.arcgis.com/home/item.html?id=0fa52a75d9ba4abcad6b88bb6285fae1.

179. Wu, B. M., and J. P. Hine. “A PTAL Approach to Measuring Changes in Bus Service Accessibility.” *Transport Policy* 10, no. 4 (2003): 307–20. https://doi.org/10.1016/S0967-070X(03)00053-2.

180. Al Mamun, S., and N. Lownes. “Measuring Service Gaps.” *Transportation Research Record: Journal of the Transportation Research Board* 2217 (2011): 153–61. https://doi.org/10.3141/2217-19.

181. Delbosc, A., and G. Currie. “Using Lorenz Curves to Assess Public Transport Equity.” *Journal of Transport Geography* 19, no. 6 (2011): 1252–59. https://doi.org/10.1016/j.jtrangeo.2011.02.008.

182. Owen, A., and D. M. Levinson. *Access Across America: Transit 2014.* Publication CTS 14-11. Minneapolis, MN: Center for Transportation Studies University of Minnesota, 2014.

183. Owen, A., B. Murphy, and D. Levinson. *Access Across America: Transit 2015*. Publication CTS 16-09. Minneapolis, MN: Center for Transportation Studies University of Minnesota, 2016.

184. Grengs, J. :Nonwork Accessibility as a Social Equity Indicator.” *International Journal of Sustainable Transportation* 9, no. 1 (2015): 1–14. https://doi.org/10.1080/15568318.2012.719582.

185. Kawabata, M. “Job Access and Employment among Low-Skilled Autoless Workers in US Metropolitan Areas.” *Environment and Planning A* 35, no. 9 (2003): 1651–68.

186. Hu, L. “Job Accessibility of the Poor in Los Angeles.” *Journal of the American Planning Association* 81, no. 1 (2015): 30–45. https://doi.org/10.1080/01944363.2015.1042014.

187. Shen, Q., and T. W. Sanchez. “Residential Location, Transportation, and Welfare-to-Work in the United States: A Case Study of Milwaukee.” *Housing Policy Debate* 16, no. 3–4 (2005): 393–431. https://doi.org/10.1080/10511482.2005.9521551.

188. Blumenberg, E., and P. Ong. “Cars, Buses, and Jobs: Welfare Participants and Employment Access in Los Angeles.” *Transportation Research Record: Journal of the Transportation Research Board* 1756 (2001): 22–31. https://doi.org/10.3141/1756-03.

189. Taylor, B. D., and P. M. Ong. “Spatial Mismatch or Automobile Mismatch? An Examination of Race, Residence and Commuting in US Metropolitan Areas.” *Urban Studies* 32, no. 9 (1995): 1453–73. https://doi.org/10.1080/00420989550012348.

190. Ben-Akiva, M., and S. R. Lerman. *Discrete Choice Analysis: Theory and Application to Travel Demand*. Cambridge, MA: MIT Press, 1985.

191. Freeman, L. C. “A Set of Measures of Centrality Based on Betweenness.” *Sociometry* 40, no. 1 (1977): 35–41. https://doi.org/10.2307/3033543.

192. Freeman, L. C. "Centrality in Social Networks Conceptual Clarification." *Social Networks* 1, no. 3 (1978): 215–39. https://doi.org/10.1016/0378-8733(78)90021-7.

193. Mishra, S., T. F. Welch, and M. K. Jha. "Performance Indicators for Public Transit Connectivity in Multi-Modal Transportation Networks." *Transportation Research Part A: Policy and Practice* 46, no. 7 (2012): 1066–85. https://doi.org/10.1016/j.tra.2012.04.006.

194. Mishra, S., T. Welch, P. Torrens, C. Fu, H. Zhu, and E. Knaap." A Tool for Measuring and Visualizing Connectivity of Transit Stop, Route and Transfer Center in a Multimodal Transportation Network." *Public Transport* 7, no. 1 (2015): 77–99. https://doi.org/10.1007/s12469-014-0091-2.

195. Hadas, Y., and A. Ceder. "Public Transit Network Connectivity." *Transportation Research Record: Journal of the Transportation Research Board* 2143 (2010): 1–8. https://doi.org/10.3141/2143-01.

196. Hadas, Y. "Assessing Public Transport Systems Connectivity Based on Google Transit Data." *Journal of Transport Geography* 33 (2013): 105–16. https://doi.org/10.1016/j.jtrangeo.2013.09.015.

197. Paez, A., R. G. Mercado, S. Farber, C. Morency, and M. Roorda. "Accessibility to Health Care Facilities in Montreal Island: An Application of Relative Accessibility Indicators from the Perspective of Senior and Non-Senior Residents." *International Journal of Health Geographics* 9, no. 1 (2010): 52.

198. Farber, S., B. Ritter, and L. Fu. "Space–Time Mismatch between Transit Service and Observed Travel Patterns in the Wasatch Front, Utah: A Social Equity Perspective." *Travel Behaviour and Society* 4 (2016): 40–48. https://doi.org/10.1016/j.tbs.2016.01.001.

199. Polzin, S., R. Pendyala, and S. Navari. "Development of Time-of-Day-Based Transit Accessibility Analysis Tool." *Transportation Research Record: Journal of the Transportation Research Board* 1799 (2002): 35–41. https://doi.org/10.3141/1799-05.

200. Delbosc, A., and G. Currie. "Choice and Disadvantage in Low-Car Ownership Households." *Transport Policy* 23 (2012): 8–14. https://doi.org/10.1016/j.tranpol.2012.06.006.

201. Lovejoy, K., and S. Handy. "Social Networks as a Source of Private-Vehicle Transportation: The Practice of Getting Rides and Borrowing Vehicles among Mexican Immigrants in California." *Transportation Research Part A: Policy and Practice* 45, no. 4 (2011): 248–57. https://doi.org/10.1016/j.tra.2011.01.007.

202. Klein, N. J., and M. J. "Smart. Car Today, Gone Tomorrow: The Ephemeral Car in Low-Income, Immigrant and Minority Families." *Transportation* 44, no. 3 (2017): 495–510. https://doi.org/10.1007/s11116-015-9664-4.

203. Preston, J., and F. Rajé. "Accessibility, Mobility and Transport-Related Social Exclusion." *Journal of Transport Geography* 15, no. 3 (2007): 151–60. https://doi.org/10.1016/j.jtrangeo.2006.05.002.

204. Pucher, J., and J. L. Renne. "Socioeconomics of Urban Travel: Evidence from the 2001 NHTS." *Transportation Quarterly* 57, no. 3 (2003): 49–77.

205. Taylor, B. D., and E. A. Morris. "Public Transportation Objectives and Rider Demographics: Are Transit's Priorities Poor Public Policy?" *Transportation* 42, no. 2 (2015): 347–67. https://doi.org/10.1007/s11116-014-9547-0.

206. Golub, A., R. A. Marcantonio, and T. W. Sanchez. "Race, Space, and Struggles for Mobility: Transportation Impacts on African Americans in Oakland and the East Bay." *Urban Geography* 34, no. 5 (2013): 699–728. https://doi.org/10.1080/02723638.2013.778598.

207. Karner, A., D. Rowangould, and J. London. *We Can Get There From Here: New Perspectives on Transportation Equity.* Davis, CA: National Center for Sustainable Transportation, 2016.

208. Federal Highway Administration/Federal Transit Administration. *Implementing the Title VI Requirements in Metropolitan and Statewide Planning*. Washington, DC: US Department of Transportation, 1999.

209. Manaugh, K., M. G. Badami, and A. M. El-Geneidy. "Integrating Social Equity into Urban Transportation Planning: A Critical Evaluation of Equity Objectives and Measures in Transportation Plans in North America." *Transport Policy* 37 (2015): 167–76. https://doi.org/10.1016/j.tranpol.2014.09.013.

210. Federal Transit Administration. *Circular FTA C 4702.1B: Title VI Requirements and Guidelines for Federal Transit Administration Recipients*. Washington, DC: US Department of Transportation, 2012.

211. Federal Transit Administration. *Circular FTA C 4703.1: Environmental Justice Policy Guidance for Federal Transit Administration Recipients*. Washington, DC: US Department of Transportation, 2012.

212. Hart, N., and N. Lownes. "Urban Core Transit Access to Low-Income Jobs." *Transportation Research Record: Journal of the Transportation Research Board* 2357 (2013): 58–65. https://doi.org/10.3141/2357-07.

213. Ricciardi, A. M., J. Xia, and G. Currie. "Exploring Public Transport Equity between Separate Disadvantaged Cohorts: A Case Study in Perth, Australia." *Journal of Transport Geography* 43 (2015): 111–22. https://doi.org/10.1016/j.jtrangeo.2015.01.011.

214. Jiao, J. "Identifying Transit Deserts in Major Texas Cities Where the Supplies Missed the Demands." *Journal of Transport and Land Use* 10, no. 1 (2017): 529–40.

215. Cardozo, O. D., J. C. García-Palomares, and J. Gutiérrez. "Application of Geographically Weighted Regression to the Direct Forecasting of Transit Ridership at Station-Level." *Applied Geography* 34 (2012): 548–58. https://doi.org/10.1016/j.apgeog.2012.01.005.

216. Kuby, M., A. Barranda, and C. Upchurch. "Factors Influencing Light-Rail Station Boardings in the United States." *Transportation Research Part A: Policy and Practice* 38, no. 3 (2004): 223–47. https://doi.org/10.1016/j.tra.2003.10.006.

217. Upchurch, C., and M. Kuby. "Evaluating Light Rail Sketch Planning: Actual versus Predicted Station Boardings in Phoenix." *Transportation* 41, no. 1 (2014): 173–92. https://doi.org/10.1007/s11116-013-9499-9.

218. Murray, A. T., and R. Davis. "Equity in Regional Service Provision." *Journal of Regional Science* 41, no. 4 (2001): 557–600. https://doi.org/10.1111/0022-4146.00233.

219. Currie, G. "Gap Analysis of Public Transport Needs: Measuring Spatial Distribution of Public Transport Needs and Identifying Gaps in the Quality of Public Transport Provision." *Transportation Research Record: Journal of the Transportation Research Board* 1895 (2004): 137–46. https://doi.org/10.3141/1895-18.

220. Jaramillo, C., C. Lizárraga, and A. L. Grindlay. "Spatial Disparity in Transport Social Needs and Public Transport Provision in Santiago de Cali (Colombia)." *Journal of Transport Geography* 24 (2012): 340–57. https://doi.org/10.1016/j.jtrangeo.2012.04.014.

221. Tribby, C. P., and P. A. Zandbergen. “High-Resolution Spatio-Temporal Modeling of Public Transit Accessibility.” *Applied Geography* 34 (2012): 345–55. https://doi.org/10.1016/j.apgeog.2011.12.008.

222. Foth, N., K. Manaugh, and A. M. El-Geneidy. “Towards Equitable Transit: Examining Transit Accessibility and Social Need in Toronto, Canada, 1996–2006.” *Journal of Transport Geography* 29 (2013): 1–10. https://doi.org/10.1016/j.jtrangeo.2012.12.008.

223. El-Geneidy, A., D. Levinson, E. Diab, G. Boisjoly, D. Verbich, and C. Loong. “The Cost of Equity: Assessing Transit Accessibility and Social Disparity Using Total Travel Cost.” *Transportation Research Part A: Policy and Practice* 91, Supplement C (2016): 302–16. https://doi.org/10.1016/j.tra.2016.07.003.

224. Federal Transit Administration. “An Overview of STOPS.” *FTA*. https://www.transit.dot.gov/funding/grant-programs/capital-investments/overview-stops.

225. Federal Transit Administration and RSG. DRAFT Simplified Trips-on-Project Software User Guide Version 2.10. Accessed March 12, 2018.

226. Metropolitan Government of Nashville and Davidson County. *Let’s Move Nashville: Transit Improvement Program*, 2017.

227. Metropolitan Government of Nashville and Davidson County. *Let’s Move Nashville: Ridership Forecasting Technical Memorandum*, 2017.

228. Bunner, R. “The TBEST Framework for Data Analysis and Forecasting.” Presentation at the Center for Urban Transportation Research, September 17, 2013.

229. Polzin, S., and R. Bunner. “Introduction to TBEST: An FDOT Model for Short Range Transit Ridership Forecasting.” Webinar presentation, June 20, 2011.

230. Bunner, R. “Utilizing TBEST for Comprehensive Transit Planning.” Center for Urban Transportation Research, Webcast Recording, March 2, 2017.

231. Bunner, R., S. Polzin, and X. Chu. *TBEST 4.4 User Guide*.

232. University of Minnesota. “Accessibility Observatory: About.” http://access.umn.edu/about/.

233. Owen, A., and D. Levinson. *Access Across America: Transit 2014*. Minneapolis, MN: Accessibility Observatory, Minneapolis, University of Minnesota, 2014.

234. Owen, A., and D. M. Levinson. *Access Across America: Transit 2014 Methodology*. Publication CTS 14-12. Minneapolis, MN: Center for Transportation Studies University of Minnesota, 2014.

235. Sugar - TransitWiki. https://www.transitwiki.org/TransitWiki/index.php/Sugar.

236. Citilabs. “Sugar Access.” *Citilabs*. http://www.citilabs.com/software/sugar/sugar-access/.

237. Governors’ Institute on Community Design. *The Why and How of Measuring Access to Opportunity: A Guide to Performance Management*, 2017.

238. Virginia Department of Transportation. “SMART SCALE: Funding the Right Transportation Projects.” http://www.vasmartscale.org/about/default.asp.

239. Citilabs. “Citilabs’ Sugar Access Enables Transportation Project Scoring for Virginia.” *Citilabs*. http://www.citilabs.com/citilabs_blog/citilabs-sugar-access-enables-transportation-project-scoring-virginia/.

240. Conveyal. “Conveyal Analysis.” *Conveyal Analysis*. http://analysis-ui.readthedocs.io/en/latest/#conveyal-analysis.

241. Conveyal. “Introducing Transport Analyst.” *Conveyal*. https://blog.conveyal.com/introducing-transport-analyst-7f0b3c595fb6.

242. Conveyal. “Client Projects.” *Conveyal*. https://www.conveyal.com/clients/.

243. Conveyal. “Preparing Data Inputs for Scenario Editor.” *Conveyal Analysis*. http://analysis-ui.readthedocs.io/en/latest/prepare-inputs/.

244. Conveyal. “Editing Transport Scenarios.” *Conveyal Analysis*. http://analysis-ui.readthedocs.io/en/latest/edit-scenario/.

245. Conveyal. “Generating Reports.” *Conveyal Analysis Documentation*. http://analysis-ui.readthedocs.io/en/latest/report/.

246. Remix - TransitWiki. https://www.transitwiki.org/TransitWiki/index.php/Remix.

247. Remix. “Remix Planning.” https://www.remix.com/planning.

248. Budds, D., and D. Budds. “The Small Startup That’s Helping Hundreds of Cities Visualize the Future.” *Co.Design*. https://www.fastcodesign.com/90110622/this-startup-is-quietly-helping-hundreds-of-cities-visualize-the-future.

249. Customer Stories. *Remix*. https://blog.remix.com/tagged/customer-stories.

250. Puget Sound Regional Council. *Remix Evaluation Report*, 2017.

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https://www.transit.dot.gov/about/research-innovation