NITC
NATIONAL INSTITUTE for TRANSPORTATION and COMMUNITIES

Final Report 1140
October 2024

Evaluating Improved Transit Connections for Ladders of Opportunity

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NITC-RR-1140

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JUNE 2024

Technical Report Documentation Page

1. Report No. NITC-RR-UTA-05	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluating Improved Transit Connections for Ladders of Opportunity		5. Report Date June 2024 6. Performing Organization Code
7. Author(s) Stephen Mattingly, Yi-Chang Chiu, Noelle Fields, Courtney Cronley, and Kate Hyun with Vivian J. Miller, Nithisha Gudipati, Jobaidul Alam Boni, Shirin Kamali Rad, Sheida Khademi, and Saeed Reza Ramezanpour Nargesi		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Texas at Arlington 211 South Cooper Street Arlington, TX 76019		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Institute for Transportation and Communities (NITC) P.O. Box 751 Portland, OR 97207		13. Type of Report and Period Covered Final Report Sept. 2017- June 2024 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Public transit facilities provide access to work, healthy food, medical care, education, recreation, and social interactions; however, this access may not be shared equitably across space or demographic groups. When equity does not appear to exist, community leaders may perceive a misalignment between transportation priorities and community needs. This study adopts a community based participatory research (CBPR) approach to provide a bottom-up strategy to identify the transportation needs of transportation-disadvantaged populations. The study uses these needs to develop performance measures that evaluate a transit network's access to opportunities as part of a methodological framework for identifying potential transportation system gaps for environmental justice (EJ) populations. The methodology defines access needs for subsets of the EJ population to provide additional guidance on prioritizing first and last mile (FLM) access needs.

17. Key Words Innovative technology; Interdisciplinary work; Transportation planning; Environmental justice	18. Distribution Statement No restrictions. Copies available from NITC: www.nitc-utc.net

19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages: 144	22. Price

ACKNOWLEDGEMENTS

This project was funded by the *National Institute for Transportation and Communities (NITC; grant number UTA-05)*, a U.S. DOT University Transportation Center.

The authors would also like to acknowledge partial support from the Department of Civil Engineering, the School of Social Work, and the Office of Research at University of Texas at Arlington.

DISCLAIMER

RECOMMENDED CITATION

Stephen Mattingly, Yi-Chang Chiu, Noelle Fields, Courtney Cronley, Vivian J. Miller, Nithisha Reddy Gudipati, Jobaidul Alam Boni, Shirin Kamali Rad, Sheida Khademi, Saeed Reza Ramezanpour Nargesi. Evaluating Improved Transit Connections for Ladders of Opportunity. NITC-RR-UTA-05. Portland, OR: Transportation Research and Education Center (TREC), 2024.

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EXECUTIVE SUMMARY

This study emphasized a bottom-up approach to defining the effectiveness of transit systems and the strategies used to access them. This research utilized the methods of community-based participatory research (CBPR) to involve people who are often marginalized within planning processes by targeting the environmental justice (EJ) population who relied on public transit more than others because they are old, disabled or under financial restrictions, and usually transit captive. The interactions with these populations identified numerous issues that impact their willingness and ability to use the public transportation system. For these communities, affordability, incentives and other encouragement to use public transportation increases their likelihood to use public transportation without creating a financial hardship for their household. Accessibility and inconvenience caused by limited service hours directly impact the utility of the public transportation system to meet the needs of all community members. These issues may become barriers and contribute to missed opportunities. A lack of affordable and effective transportation may cause a vicious cycle for these populations and communities because they cannot reach essential services and jobs.

The study uses the findings from the CBPR to inform the remainder of the research work. After investigating the state-of-practice and state-of-art performance measures previously utilized by transit agencies and researchers, this report identifies and defines performance measures that align with the needs and barriers of the EJ population. These measures emphasize access to opportunities, equity, and affordability, but also include many other issues that impact or concern these communities. Safety, security, reliability, assistive services, operating schedule, and the built environment directly affect their ability to characterize public transportation as a viable transportation alternative. When considering first and last mile (FLM) access strategies, the economic viability and sustainability of the strategy and partner represent a central concern for transit agencies.

The study develops a method for assessing the access to opportunities, equity, and affordability performance measures and applies this method to the Dallas Area Rapid Transit System in Dallas County, Texas. In Dallas County, most of the non-auto FLM strategies are affordable for most households; however, ride hailing and ride share demonstrate limited affordability as a viable FLM access strategy for households with an annual income less than $125,000. This significantly limits the effectiveness of the DART system for low-income households unless their opportunities, like food, healthcare, jobs and education are close to a transit stop and they live near a transit stop. The FLM alternatives produce the following outcomes in Dallas County:

Walking: Limited due to the shortest buffer radius, but crucial for immediate access around transit stops.

Biking and E-Scooters: Provide better access than walking, with e-scooters showing the best results among non-motorized options.

Ride-Hailing: Offers the most extensive coverage and fastest travel times, but is often unaffordable for many EJ populations.

The study emphasized the need for affordable and accessible FLM solutions tailored to the needs of different demographic groups within the EJ population. The study highlighted the importance of shifting transportation planning towards equity by ensuring all community members have access to essential services and opportunities. Spatial analysis techniques identified areas with significant gaps in transit accessibility. This provided information crucial for transportation agencies to prioritize investments and improve service delivery to underserved areas. A brief knowledge of the entire study and the analysis were provided in the last chapter highlighting the key findings.

1 INTRODUCTION

Participation in modern societies requires transportation systems because effective transportation systems connect people to opportunities that are spatially distributed throughout the built and unbuilt environment. Highways, public transit lines, and non-motorized facilities facilitate access to work, healthy food, medical care, education, recreation, and social interactions (Cozart, 2016). Often, the distribution of access to these activities does not occur equitably across space or demographic groups (Bullard et al., 2003; Ihlanfeldt & Sjoquist, 1998; Mirchandani & Lucas, 2004; Taylor & Ong, 1995) because historical and ongoing planning practices and investment decisions tend to disadvantage those who live far from transportation infrastructure and who choose to or cannot afford to drive (Golub et al., 2013; Henderson, 2006). The prioritization of auto travel significantly contributes to the system failing to serve segments of the population effectively. Figure 1 displays the different opportunities people access using public transit; these opportunities may be prioritized based on human needs.

Figure 1.1: Ladders of Opportunities Accessible by Transit

The environmental justice (EJ) population, which includes older adults, racial and ethnic minorities, persons of low income, persons with limited English proficiency, children, persons with disabilities, female heads of households, and zero-car households (Federal Highway Administration, 2017) remain more likely to rely on public transportation on a regular basis than others (Anderson, 2016). For EJ cases, effective transportation is one of the primary barriers that blocks low-income individuals' paths out of poverty (Wachs, 2010; Blumenberga & Agrawal, 2014). Transportation disadvantage can have detrimental implications on individuals' overall quality of life, employment, education, healthcare, social activities, and nutrition (Adorno et al., 2016; Fol & Gallez, 2014; Jones & Lucas, 2012). The EJ population represents most of the transit-captive residents, and they must consider transit access when selecting a residence.

Affordable housing in many U.S. cities may not always align well with the location of the transit system. Transit in many U.S. cities is rarely capable of delivering travelers all the way from their point of origin to their destination, which is often called the first-and-last

mile (FLM) problem (Zuo et al., 2020). Figure 2 shows a description of first and last mile (FLM) graphically.

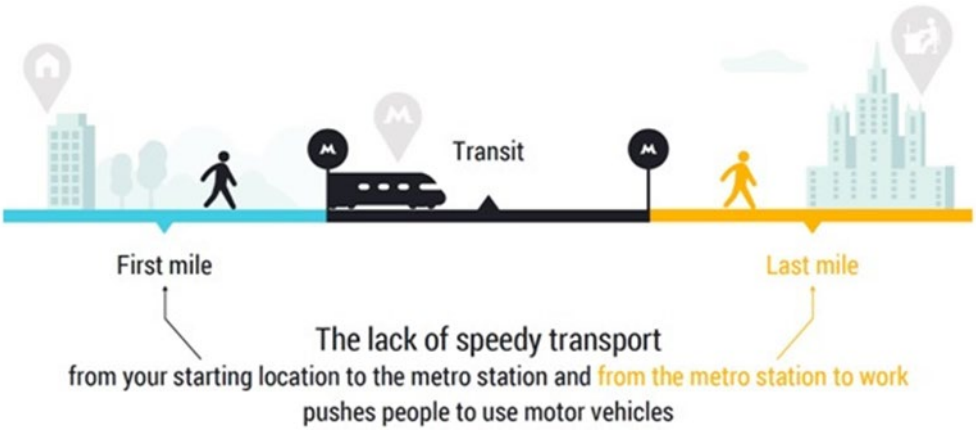


Figure 1.2: FLM Definition

Typically, transit riders can be classified into two groups: those who use transit by choice and those who use transit because they have no other viable option. Choice users use transit because they have a realistic transit option available that connects their origin and destination at a time and within a duration that meets their needs and works within the constraints of their household and life situation. Travelers choose transit then they feel that the transit option is superior or competitive to other choices considering time, cost, convenience, and comfort. In contrast, captive-transit users may be bound to public transportation because of age, disability, income, or family circumstances. Similarly, those without access to transit can be divided into two groups: those who can still travel using an automobile or some other mode and those who cannot travel at all. Automobile-dependent households may occur in areas without access to public transportation; however, when these households do not own a car, they cannot complete any trips without transportation service provided by another party (Beimborn et al., 2003). Figure 3 displays the modes available to households to classify the modal dependency of people making mode decisions.

This FLM problem appears to deter transit use among choice riders (Wang & Odoni, 2016) and eliminates mobility altogether for the transit-captive population (Zellner et al., 2016). The first-and-last mile represents a major element of a transit trip for the non-driver EJ population, and it determines whether transit service is reachable or not (Zuo et al., 2020). Thus, transportation gaps among persons of color and other low-income persons contribute to missed opportunities and social exclusion (Cornwell & Waite, 2009). Inadequate FLM alternatives may make gaps in the transportation system more pronounced for portions of the EJ population.

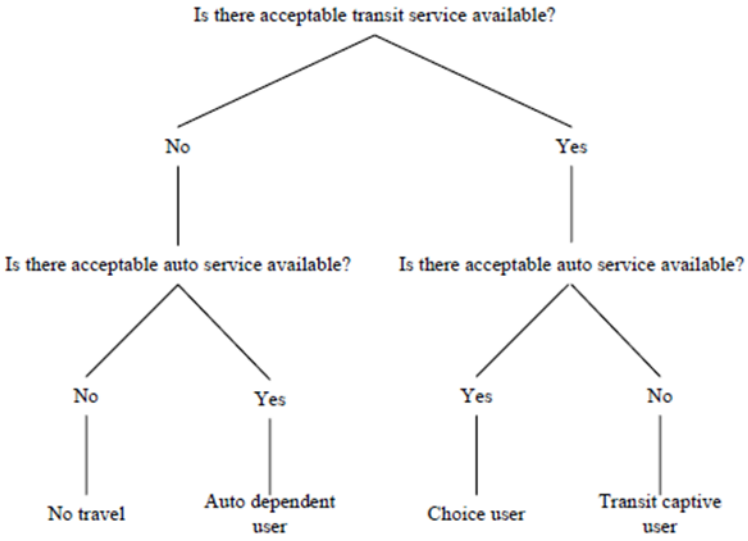


Figure 1.3: Trip Decision Process

1.1 Gaps in the Knowledge

Transportation systems provide accessibility to desired destinations for individuals and impact their quality of life. The social aspect of mobility is neglected in the current model of transportation planning, which indicates the need for significant changes to change the focus of planning to quality of life (Boisjoly & Yengoh, 2017). The current top-down conventional planning approach typically emphasizes traffic flows and minimum travel times (Handy, 2008; Proffitt et al., 2019); however, recent research recognizes the need for local and participatory approaches in transportation planning (Banister, 2008). This shift in goals for transportation planning enables it to address the needs of all members of the population using a bottom-up approach like scenario planning.

Transportation planning has a long and fraught history of creating social and environmental injustices. Scholars have discussed the issue of varied levels of access to opportunity, and often suggest that accessibility represents the best framework for considering equity in transportation. The FLM problem represents one of the major barriers to transit accessibility, and minimizing the FLM gap can reduce transportation disadvantage (Zuo et al., 2020). While accessibility (e.g., Kain, 1968; Taylor & Ong, 1995; Shen, 2001; Grengs, 2010) and first-last mile transit access (e.g., Lesh, 2013; Wang & Liu, 2013) have been extensively studied, the previous works in literature and practice have overlooked an important relationship between station or stop access/egress as part of the equity characteristics of transit accessibility (Boarnet et al., 2017). Thus, meeting the FLM needs in vulnerable communities represents a key strategy for addressing previous injustices, but the FLM access strategies require further investigation to identify the EJ population's interactions with FLM alternatives.

Previous transit-related studies mostly emphasize mobility and stop-to-stop travel time between traffic analysis zones. While mobility represents a key goal in the transportation system, the EJ population, specifically the non-drivers or transit captive, require transit

coverage and accessibility to avoid missed opportunities and social exclusion. For people who rely on transit as their main transportation mode, reasonable access to transit represents the fundamental prerequisite for reaching their desired activities. Individuals lacking accessibility to places such as jobs, education, and child care are transportation disadvantaged (Foth et al., 2013; Jones & Lucas, 2012; McCray & Brais, 2007) and will suffer from inequity. This occurs specifically for captive-transit users who may be bound to public transportation because of age, disability, income, or family circumstances, so they cannot complete any trips without transportation service provided by another party (Beimborn et al., 2003). In fact, transportation equity concerns over transport disadvantage should focus primarily on accessibility as a human capability. A full account of equity in transportation requires a more complete understanding of accessibility than traditional approaches have been able to deliver to date (Pereira et al., 2017), which presents a methodological challenge. Planning for equitable outcomes in transportation requires the development of evaluation methods that support the integration of equity in planning processes (Brodie & Amekudzi-Kennedy, 2017). Improving transit-based accessibility to a wider range of opportunities by providing FLM options appears vital to advance a more equitable society.

This study creates a methodology to evaluate transit connections regarding access to opportunities and the transportation gaps of EJ populations. This study formulates four sub-objectives: 1) Performance Measure (PM) development based on the literature and a community-based participatory research (CBPR) approach; 2) Accessibility Index; 3) Spatial analysis of both metrics in ArcGIS using clustering and hot spot analysis; and 4) Integration of indices to find transportation gaps. The authors apply the method on the Dallas Area Rapid Transit (DART) system in Dallas County, Texas, to show its ability to find transit gaps for vulnerable populations. The research contributes to help transportation agencies with identifying areas in need of service improvement and enhanced FLM access to prioritize future investments and potential introduction of on-demand services.

1.2 EJ Needs Identification

The research utilized the methods of community-based participatory research (CBPR) to involve people who are often marginalized within planning processes. The research team assembled a Community Advisory Board (CAB) comprised of transportation experts, partners, and other providers of social services to EJ populations using a snowball sample, with key stakeholders recommending community professionals (e.g., metropolitan planning organizations and city officials); social workers and direct practice workers (e.g., homeless shelters, senior center, nursing association); and transportation planners (e.g., local transit authority). This structure of the CAB aimed at guiding and supporting the data collection process with the community. The CAB also reviewed and provided feedback on the recommended performance measures necessary to better assess transit service based on equity, health, and access to opportunities. The CBPR

structure with a CAB supported most of the deficiencies identified in the literature related to public involvement and EJ population participation (Fields et al., 2020).

The CBPR data collection implemented surveys and interviews to solicit the lived experience of the transit-captive population and identify their transportation needs. As recommended by the CAB, the CBPR held three focus groups with stakeholders across the community. A total of 25 participants from a wide array of organizations shared their perspectives on the first/last mile issue and its impact on transportation accessibility among EJ populations. The focus group participants represented agencies including, but not limited to, Lyft Marketing, City of Mesquite, Freedom House, City of Arlington, MyRide, City of Dallas, and local independent school districts. In addition, the study conducted interviews and an online survey to identify the transit-captive community's lived experience and transportation needs. The interview sought to improve the transportation system for individuals who may have difficulty accessing reliable transportation and included 18 individuals across the community. The targeted participants from the EJ population included homebound older adults, unaccompanied homeless young adults, parents in emergency family shelters, and racial/ethnic minorities. The participants completed an additional survey, which collected their perspectives on the first/last mile and its impact on transportation accessibility, in person at the time of their in-depth interviews. The stakeholders supplemented the recruitment of the 65 survey participants. All interviewees and survey participants were recruited through social service providers in North Texas.

2 BRIDGING THE FIRST/LAST MILE PASSENGER GAP

2.1 INTRODUCTION

Transit agencies collaborate with stakeholders to establish innovative public/private pilot projects to reduce the distance between a traveler's origin/destination and a transit station/stop, which is commonly referred to as the first/last mile. Currently, many private companies compete to fill this gap with and without partnerships with transit agencies. Uber, Lyft, and other taxies offer rides (rideshare) from/to the stations. Unfortunately, transit ridership (in general) and the target EJ population remain sensitive to the fares, and these private solutions often add significantly to the transit service cost. These factors require an evaluation of transit ridership to include the fare elasticity and any government subsidy of FLM rideshare or other services for EJ populations, like the elderly, disabled, poor and homeless. Public transit's goals must include providing transportation to opportunities for all individuals to participate in the economy. Furthermore, the effectiveness of these strategies must consider that not all populations in need of service and access to opportunities may have access to the internet, smartphones, and electronic banking.

This section presents FLM alternatives, use cases and examples to demonstrate their theoretical roles and applications in cities. These strategies can potentially play a pivotal role in bridging gaps in the existing transportation network and encouraging multimodality for first-and last-mile trips rather than driving alone. For all the alternatives, both choice and captive riders must be included in the assessment because they have different needs and often experience different total costs when choosing to travel.

2.2 FIRST MILE LAST MILE STRATEGIES

Increased route coverage with fixed route deviations or fixed route feeder services often does not represent a cost-effective solution for increasing ridership. As a result, other FLM strategies must be used to increase choice riders and provide more mobility for captive riders. The current decline in transit ridership emphasizes the need for new FLM strategies to support greater utilization of urban mass transit. Fortunately, information and vehicular technology innovation, as well as disruptive person-to-person (P2P) and public-private-partnership (3P) delivery models provide new strategies to bridge the FLM passenger gap and enhance urban mobility. From traditional to the cutting edge, the range of FLM connective modes, technologies and delivery models include many options that can be organized into four modal groups (Table 1).

2.2.1 WALKING

By far, the most important first mile/last mile connection is walking as over 90% of transit riders walk to and from the bus. With good walking conditions,

passengers will walk farther, increasing the reach of transit. Where gaps exist in the pedestrian network, people will not walk as far.

Table 2.1: FLM Option Categories

			
Pedestrian Modal Group	**Bicycle, Board & Skate Modal Group**	**Vehicular Modal Group**	**Transit Modal Group**
• **Walking** • **Special needs for elderly or people using wheelchairs**	• Personal Bicycles • Bike Sharing • E-Bikes and E-bike Sharing • Skateboards • Electric Skateboards • Foot Skates • Segway and other Personal Mobility	• Park-and-Ride • Kiss-and-Ride • Park-and-Ride with Plug-In Electric Vehicles (PEV) • Neighborhood Electric Vehicles (NEV) • Car Sharing: -Networks -Ride -Hailing/Sharing & -Traditional Taxi • Autonomous Vehicles (AV) Station Cars	• Conventional Transit Services - Public Provider • Micro Transit - Private Providers and some P3 • Advanced Group Rapid Transit (GRT) • Aerial Cable Transit (ACT)

Coverage: If environmental considerations are set aside, the answer to the question of how far people walk to transit has great variability by age, gender, ambulatory status, and possibly even cultural biases. Notwithstanding that variance from person to person can be significant, research has a consensus on a walking distance range of a quarter mile to a half mile as maximums for the general population, which represents about a five to 15-minute walk.

Some evidence also indicates that walk distance varies by whether the walk is to/from the home to the transit station (production-end), or to/from the station to work, shopping or other destination (attraction-end). The home side of the trip (first mile), appears to allow for longer walking distances than the destination side (last mile). Transit-Oriented Development (TOD) guidelines also suggest differential walking distances by origin and destination type, summarized in Table 2.

Cost: Walking also represents the lowest cost first mile/last mile connection, because it is free to both users and transit providers.

Special needs for elderly or people using wheelchairs: For people using wheelchairs, research establishes trip length guidelines for a single non-stop trip distance of about 600 feet for people in self-propelled wheelchairs, and about 1,130 feet for powered wheelchairs. Using the average speeds for self-propelled wheelchairs and most powered wheelchairs (some travel up to speeds of 10 mph), this corresponds to approximately three-minute trip times for each.

Table 2.2: Walk Distance & Time by Origin/ Destination

Mode	Employment	Home
Walk Distance	500-1000 ft	1/4 – ½ miles 1320 - 2640 ft
Walk Time @ 3.16 mph	2-4 minutes	5- 10 minutes

2.2.2 BICYCLE & PERSONAL URBAN MOBILITY OPTIONS

Bicycling represents another cost-effective mode for people to access transit because it has relatively low costs for users and no operating costs for transit systems. Bicyclists can travel significantly longer distances than pedestrians and bicycling has become a more important mode for journeys to work over recent decades (Transit Forward 2040, 2019).

Coverage: Average home-based work trips are in the maximum of 10 to 20 miles each way for these trips; however, this analysis is concerned with the use of bicycles and personal urban mobility options as FLM strategies.

Cost: Cost of owning the equipment varies in a wide range starting from $100. The average cost of shared bike options is between $1 to $4 per hour. Costs associated with each of the bicycle and personal urban mobility options appear in Table 3.

Examples: When transit agencies want to invest in expanding access using bicycles and other personal urban mobility modes, they can provide shared-use fleets. Often, transit agencies select a single shared-use fleet. As part of Baltimore Link, the Maryland Department of Transportation's (MDOT) Maryland Transit Administration (MTA) partnered with Baltimore City to install bikeshare stations at 11 MDOT MTA rail stations, primarily in the downtown business district ("Public Transit GM Q&A: How Are You Solving the First/Last Mile Issue?", n.d.). The Sacramento Regional Transit District (SacRT) provides an e-bike program as a micro-mobility strategy to address the FLM problem. The agency offers on-demand access to/from light rail stations (APTA Admin, n.d.). In other cases, a transit agency may decide to invest in providing a suite of sharable alternatives to reach a broader range of the population. RideKC operates as a partnership of the Kansas City Area Transportation Authority, BikeWalkKC, and Drop Mobility. The system provides a unique integration of public transit and shared use mobility.

Three fleets of traditional pedal bikes, electric-assist bikes, and scooters provide residents and visitors with healthy, sustainable options for getting around Kansas City. While most transit agencies emphasize bike shares, this Kansas City example demonstrates that other personal urban mobility options like scooters may also help increase transit access.

Bicycle-sharing programs have experienced rapid growth in North America, presenting an affordable, suitable, and sustainable travel option with various advantages. Another benefit of bicycle-sharing programs is that the programs may improve transit ridership. The analysis of the interaction of Metrorail and Capital Bikeshare (CaBi) in Washington, D.C., leads to two major conclusions. First, Metrorail stations have been important origins and destinations for CaBi trips. Almost all CaBi stations with the highest ridership are located close to Metrorail stations, and some have good accessibility to multiple stations. Second, CaBi's impact on Metrorail ridership is statistically significant: a 10% increase in CaBi trips would generate a 2.8% increase in transit ridership (Ma et al., 2015).

As part of a menu of urban transportation options, scooters have the potential to reduce short-distance, single-occupancy vehicle and transportation network company (e.g., Uber, Lyft, Via) trips and enhance access to transit, which reduces urban congestion and emissions. Scooters offer an option that most working-age people, regardless of fitness or ability, can ride for short trips ("E-Scooters Could Be a Last-Mile Solution for Everyone", 2018). In recent years, companies such as BIRD, LIMEBIKE, and OFO have established transit/transportation companies and invested in solving the FLM problem by offering reliable electric scooter rental service. They provide users a fun way to get from point A to point B and represent an emerging FLM alternative. ("What Is the 'First Mile, Last Mile' Problem?", 2018).

2.2.3 VEHICULAR MODAL GROUP

The vehicular options provide the most universal access to transit and traditionally represent the most common and readily implementable solutions. The vehicular FLM strategies comprise both traditional examples like a park-and-ride and emerging examples like neighborhood electric vehicles in an expanding modal group influenced by technological advances and business model innovation. This FLM modal group includes many vehicle types, propulsion types, guidance, and business models in the following categories:

Park-and-Ride & Kiss-and-Ride

- Park-and-Ride, Plug-In Electric (PEV)
- Neighborhood Electric Vehicles (NEV), Urban Electric Cars
- Car Sharing: Commercial Pod-based, Free Floating, Station Cars, and Peer-to-Peer Networks
- Ride Sharing & Traditional Taxi

Cost: The geographic location of parking lots influences their construction and operating costs. Transit agencies may choose to pass these costs along to users by generating revenue at the park-and-ride lots through parking fees, or the agency may absorb the costs to try to increase choice riders.

Partnerships between transit systems and ride hailing companies like Uber and Lyft provide subsidized service to transit users. The actual services that are provided are very similar to taxi service, but with app-based reservations and fare payment. The high cost of these partnerships represents a major challenge for transit agencies because the typical fare starts at around $7. This enhanced access imposes a high cost to riders and/or transit systems (Transit Forward 2040, 2019).

Examples: San Francisco Bay Area Rapid Transit (BART) plans to enhance access and augment park-and-ride capacity by offering an integrated carpool-to-transit program that will help users find carpool matches as well as match them to their transit destinations (APTAAdmin, n.d.). -The project provides a seamless way to reserve and pay for parking spaces at BART stations and allows for preferential parking for carpoolers while increasing transit ridership by improving access to BART stations. The software includes ways to identify drivers with wheelchair-accessible vehicles. The project is part of the FY 2016 Mobility on Demand Sandbox (MOD) Grant Program (APTA, 2019). Furthermore, car sharing, such as ZipCar and Car2Go, can provide a high level of access and flexibility; however, it probably works best for occasional transit users and for long-distance modes like intercity rail using a park-and-ride lot ("Last Mile Connections – TransitWiki," n.d.).

2.2.4 TRANSIT MODAL GROUP

Integrated ride sourcing services can enhance transit systems in two principal ways. First, ride sourcing could be used as a replacement for fixed-route transit lines in low-demand areas in order to increase operational efficiency. To meet the political and service needs of geographic coverage, transit operators often need to run transit lines in low-density areas that produce very low ridership, particularly during the evenings and weekends. Operating an on-demand, flexible-routing transit system to replace these lines or certain segments of them may be able to serve existing transit demand while reducing costs by replacing large buses with cars or other small vehicles with reduced capital and operating costs. Second, ride sourcing can complement transit because it can relax the constraints caused by fixed routes and vehicle scheduling. For people who do not live within walking distance of a transit stop, this may provide suitable last-mile connections between the point of origin/destination and the transit network and expand the catchment area of public transit (Yan et al., 2019). Micro transit represents a new term for app-based services that use smaller vehicles to transport low volumes of people.

Cost: Like rideshare partnerships, the high cost of micro transit poses a major challenge because the typical cost per trip for micro transit service is $10 or higher (and sometimes much higher). Typically, most of this cost is borne by transit systems (Transit Forward 2040, 2019).

Examples: FLM transit solutions easily fit into a transit agency's existing business model; however, they often experience higher costs because transit agencies operate as ride share aggregators using a fixed schedule. Many agencies absorb the additional cost of increasing system access to try to increase the total number of aggregated trips and reduce congestion. Emeryville, CA, provides a free shuttle bus system to provide access to the nearest BART station ("Last Mile Connections – TransitWiki," n.d.). Trinity Metro (Fort Worth, TX, area) started a new first/last mile solution named ZIPZONE, which connects TEXRail and bus commuters who travel from/to the Mercantile Center Station (APTAAdmin, n.d.) along a fixed route. In all cases, greater access requires the transit agencies to keep the fare as low as possible for the local routes.

Transit agencies may also opt to partner with a private provider if they can enhance access more efficiently than the transit agency itself. LA Metro launched a pilot program with Via, a Micro transit company, to offer shared, on-demand rides to and from three LA Metro stations that serve minority and low-income communities. Fares are $1.75 for riders with a TAP (Transit Access Pass) card, $3.75 for riders who do not provide a TAP card number, and free for participants of Metro's low-income fare subsidy program. Customers without smartphones may hail rides by telephone, and those without access to credit cards may pay using debit or prepaid cards (Transit Forward 2040, 2019). FLM transit solutions use familiar business models and strategies to enhance transit access.

2.3 COMPARISON BETWEEN DIFFERENT FLM OPTIONS

An individual's preference to use fixed-route transit for a linked journey, is dependent on comparative preferences about real and perceived travel advantages, such as: journey time, wait time, reliability, comfort, security, convenience, integrated real-time travel information, multitasking connectivity, and out-of-pocket cost.

Individuals demand a transport system that is both flexible and convenient. Most travelers prefer the automobile because it provides door-to-door service with limited out-of-vehicle waiting and access time. This reality increases VMT and compounds congestion and related environmental impacts. This section compares some of the policies and strategies planners and operators have developed to meet the FLM challenge. The characteristics of each of the FLM options have been summarized in Table 3. This table displays coverage, speed, distance and costs associated with each of the FLM options. Understandably, vehicular and micro transit modes provide more coverage than pedestrian and bike options due to higher speed. However, the mentioned FLM strategies are expensive in terms of equipment costs or rental costs and they may not be affordable for disadvantaged populations.

Table 2.3 Comparison between Different FLM Options

Modal Groups	Options	Coverage	Speed	Distance	Cost of Equipment	Rental Cost[1]	Avg cost per daily FLM[2]
 Pedestrian	**Walking**	0.25-0.5 mi	3 mph	5-10 min	$0	$0	$0
	Special needs for elderly or people using wheelchairs	600-1130 ft	3 to 5 mph	3-5 min	$0	$0	$0
 Bicycle, Board & Skate	**Personal Bicycles**	3 mi	15-20 mph	9-12 min	$100-$3500	$0	$0.46
	Bike Sharing	3 mi	15-20 mph	9-12 min	$0	$1-4	$ 0.4
	Personal E-Bikes	3 mi	20 mph	9 min	$1000	$0	$0.5
	E-bike Sharing	3 mi	10-15 mph	9-12 min	$0	$2	$0.6
	Skateboards	1.3 mi	10-15 mph	5-8 min	$50-$300	$0	$0.07
	Electric Skateboards	1.5 mi	10-15 mph	5-10 min	$1200-$1500	$0	$0.24
	Foot Skates	2.3 mi	10-15 mph	10-15 min	$200-$400	$0	$0.12
	Segway	2.3 mi	12 mph	12 min	$6000	$0	$1.95
	Rental Segway	2.3 mi	12 mph	12 min	$0	$25-$40	$16.25
 Vehicular	**Park-and-Ride, & Kiss-and-Ride**	5-10 mi	50 mph	5-12 min	$2-$5	$0	$0
	Car Sharing	10-20 mi	35 mph	15-35 min	$2000+	$0	$0
	Ride Sharing & Taxi	10-20 mi	35 mph	15-35 min	$7+	$0	$0
 Transit	**Micro Transit**	10-20 miles	25 mph	24-48 min	$10	$0	$0

(Adopted from First Last Mile technical Report by Corradino group, 2018)

[1] For half an hour
[2] For two 10-min trips/day

2.4 DEMAND RESPONSIVE TRANSIT

Demand Responsive Transit (DRT) in Europe, or paratransit in the U.S., provides equitable transportation available to the public. The history of DRT can be traced back to the 1960s, when DRT systems were first proposed, but simple DRT systems first appeared during the 1970s in the U.S. One of the most common purposes of DRT systems is to provide accessibility to those who live in rural areas where providing regular, fixed-schedule transit is not financially viable. A large increase in DRT systems in 1990 resulted from the Americans with Disabilities Act (ADA), which required the availability of paratransit services for individuals who were unable to use fixed-route services, and Title VI of the Civil Rights Act of 1964, which required that the providers of federal funds not discriminate on the basis of race, color, and national origin. Different from regular fixed route transit, DRT systems commonly use small to medium-sized vehicles to provide shared rides or door-to-door and curb-to-curb service with flexible routes and schedules (Fu, 2002). Rather than being the dominant public transport supplier in a market, DRT services are regarded as a vital supplier of services where conventional bus service cannot reach, such as in low-demand areas where social exclusion is evident (Brake et al., 2004). Table 4 and the rest of this section describe DRT examples around the world.

Table 2.4: Examples of DRT Systems in the World

Project	City/State	Start year	Area	Fixed route?	Booking	Hours	Goal	Operator
Telebus	Melbourne	1980	The outer eastern Melbourne suburbs	Fixed stops, pick/drop	Phone, in advance	6am-midnight	Provide cost-effective public transport in a difficult area	Invicta Bus Services
Roam Zone	Adelaide	2001	Hallett Cove, Sheidow Park and Trott Park	Fixed stops	Phone, in advance	6am-11pm	Provide 'to-your-door' service at anywhere within the Roam Zone area	Adelaide Metro
momo-cow	Setouchi	2012	Ushimado	Fixed stops, pick/drop	Phone, in advance	7am-6pm	Bring more vibe to the elderly	Local government
Customized Bus	Qingdao	2013	Most schools and communities	About 10 fixed stops	Online, at most a month in advance	7am-6pm	Replace cars, alleviate congestion	Qingdao Public Transportation Business Tourism Group
Red minibus	Hongkong	1967	City	No fixed stops	Hail the minibus	24-hour	Serve areas that standard Hong Kong bus lines cannot reach efficiently	Commissioner for Transport
Pace	Chicago	1983	Throughout the suburbs	Scheduled stops	Phone, online	24-hour	Include ADA paratransit and on-demand service for general	Regional Transportation Authority
Metro Access	DC	1994	Transit Zone in the Washington Metropolitan region.	Fixed stops	Phone, online, in person	8am-4:30pm	Provide service for individuals who are unable to use fixed-route public transit due to disability	Washington Metropolitan Area Transit Authority (WMATA)
Drinbus	Genoa	2002	City	Flexible stops	Phone, on line, at least 30 minutes in advance	7am-8pm	Replace conventional buses	AMT-Public transport company in Genoa
London Dial-a-Ride	London	2002	Six sectors in London	No fixed stops	Phone, online	6am-2pm	Provide service for people with a permanent or long-term disability or health problem who are unable, or virtually unable to use public transport	Transport for London (TfL)

2.4.1. DRT in Europe: Why they appear and how they are operated and funded in the UK, Finland, Italy, Luxemburg, and Poland

Most DRT systems are designed for the elderly, and the share of people aged 80 years or more will more than double by 2080 to reach 13% of the entire population (“Population

Structure and Ageing," n.d.). After 55, car usage decreases, while public transport becomes a more frequently used alternative for those aged 75 or older (Shrestha et al., 2016). Flexible transit services (FTS) in the form of dial-a-ride services for the elderly and disabled have existed in the UK since the 1970s. However, public or open access FTS did not emerge until the 1990s. Commercial operators eliminated fixed route bus service in rural areas because it was unprofitable. This led regional and local governments to contract commercial operators to provide subsidized services. FTS represented a solution for local authorities because of its relatively low cost since the bus service relied heavily on a subsidy.

Most of the objectives of providing DRT fit into the social category, ranging from the ambiguous to social and economic, such as "promoting social inclusion," and "enhancing the quality of rural life by giving greater independence to youngsters, the elderly, and the mobility impaired." Most of the social objectives relate to increasing accessibility to locations that are currently inaccessible, such as providing access to food shopping for older and disabled people and to provide people without private transport access to jobs. Some reasons are related to economic objectives such as providing the most cost-effective service for more remote areas or meeting employer demand for workers due to expansion (Laws et al., 2015).

In the UK, most of the funding comes from the Rural Bus Challenge, Urban Bus Challenge, Local Authority, and Rural Bus Subsidy Grant, according to a survey across seven English regions with one scheme in Wales (Laws et al., 2008). The schemes operating in a purely rural area have a higher incidence of subsidies exceeding £5.00 and a lower incidence of subsidies falling into the £2.00-£5.00 range than those operating in an urban or mixed area. In addition, schemes with less than 21 seats appear more likely to have higher subsidies than larger schemes.

In Finland, to evolve the bus market and its services, Helsinki introduced a "mobility on demand" public transit service, called Kutsuplus, in 2013. It was introduced as a new carpooling/ride sharing model. This service was an on-demand transit system which was offered on a minibus. The Kutsuplus service grouped people traveling in the same direction onto a single minibus, offering the convenience of taxis at a much lower price with the efficiency of a bus (Frost & Sullivan Institute, n.d.). A new operation began in November 2018 to connect the small town of Haukipudas with the city of Oulu – the fifth largest city in Finland. The goal was to connect the main city with the town of Haukipudas, which has 20,000 inhabitants. The area of operation spanned eight kilometers squared, which two minibuses with 14 and 16 seats, respectively, covered ("A Pilot Demand Responsive Service Launches in Finland", 2018).

In Italy, the ATAF (Azienda Trasporti Area Fiorentina) dial service experience started in 1995 with the creation of a disabled people service. It included five buses on the whole road network of Florence, with a timetable from 7 a.m. to 8 p.m. In April 2002, DrinBus was provided by AMT (Azienda Mobilita e Trasporti) of Genova to test a dial-bus service. It is active in two town areas (Pegli and Quinto), where traditional buses cannot travel.

Users need to choose a departure location and destination within appropriately fixed bus stops in their zone (Archetti et al., 2018).

Kussbus is a private door-to-door bus service primarily for commuter purposes in Luxembourg. The main idea of Kussbus is to find a way to make people more likely to travel in the buses rather than their cars. Kussbus offers 19-seat buses and a (nearly) door-to-door shuttle service for people to travel to work together. One bus can potentially replace 19 cars. At the beginning, Kussbus chief executive Jean-Luc Rippinger and his business partner Nicolas Back hit a wall, as they did not have a large enough budget, so they set up a website with the aim of attracting potential investors and started a campaign in December 2016, where almost 6,000 people registered. Following this success, they met with investors who, along with the Ministry of Economics, decided to financially support Kussbus. Because Luxembourg has some of the cheapest bus transport in Europe and is also heavily funded, Kussbus, a private initiative, cannot compete with public transport fares (Ducoli, 2018).

The first demand responsive transport scheme in Poland, Tele-Bus, operated since 2007 in Krakow by MPK, the local public transport company, to serve those who live in an area where regular public transit was limited and the frequency of buses was low (“Tele-Bus Kraków,” 2019). The key partners within this activity were the local public transport company (MPK), the Municipality of Krakow, and the City Council (“New Dedicated Innovative Services - TELE-BUS. Krakow. Poland,” n.d.).

2.4.2. DRT in the U.S. and Canada

Many DRT systems have been implemented in the U.S. They are mostly funded by local transit agencies. Call-n-Ride service Pace Transit in Illinois is part of a long-term strategy aimed at developing smaller routes. The advantage of this service lies in that it maintains mobility for a lot of people within their residential area, but also provides connectivity to larger fixed routes. Call-n-Ride also helps solve the last-mile problem, which is the final leg after a suburban commuter takes a Metro train or fixed-route bus home (Wronski, 2011). FlexRide is the Regional Transportation District's (RTD's) shared-ride bus service in Colorado, available for anyone to connect to other RTD bus or train services. However, the service goes beyond bridging first- and last-mile transit connections because riders can also use Flex-Ride for direct access to schools, businesses, or other amenities in communities without a fixed bus route (Bosselman, 2019). The Denton County Transportation Authority (DCTA) has been providing curb-to-curb demand response transit services for age 65+ or disabled Frisco residents for trips within Frisco, McKinney, and Allen, as well as designated portions of Plano ("Frisco Demand Response," n.d.).

These days, many grants provide funding for more convenient transit services for the elderly. FTA Section 5310 Enhanced Mobility of Seniors and Individuals with Disabilities is a federal formula grant program. It aims to enhance the mobility of seniors and persons with disabilities by providing funds for programs to serve the special needs of transit-dependent populations beyond traditional public transportation services and ADA complementary paratransit services. Funds are apportioned to states for urban and rural areas based on the number of older adults and people with disabilities in the areas ("Section 5310," n.d.). The U.S. Department of Transportation has announced a $6.3 million funding opportunity to improve access to non-emergency healthcare, which includes paratransit in 2018 ("U.S. Department of Transportation Announces $6.3 Million Funding Opportunity to Improve Access to Healthcare," 2018). In response to increasing ridership and other paratransit service costs, in 2010 Washington Metropolitan Area Transit Authority (WMATA) made two significant changes: paratransit service areas were reduced from jurisdictional boundaries to the ADA requirement of within a three-quarter-mile corridor of fixed-route services, and fares were linked to WMATA's fixed route services and charged to the ADA allowable maximum of two times the fastest equivalent bus or rail fare ("The History of Paratransit," 2019).

BT Let's Go, operated by Belleville Transit in Canada, replaced fixed route night bus services with an on-demand transit service. This provides stop-to-stop scheduled pickups and drop-offs requested by riders through a web-based application. Buses are dynamically routed to riders in real time with an autonomous algorithm ("How Belleville, Ont., Is Using Technology to Tackle Transit Troubles - CBC Player," n.d.).

2.4.3. DRT in Asia-Pacific (China, Japan, Australia)

Red minibuses are the main form of DRT systems in Hong Kong and serve non-franchised routes across the city. Most routes are well-established by tradition, though,

so rather than requesting their destination when they board a bus, passengers know where to catch a bus heading in their direction. Minibuses seat a maximum of 16 passengers and all passengers must be seated. Once a bus fills up, it becomes an express service until the first passenger needs to get off, making it a particularly speedy way to travel long distances. In contrast to many services in North America and Europe that are mostly operated by public agencies, drivers are free agents who rent the vehicles for a shift, with a going rate of HK$800 per day. This gives them an extra incentive to drive quickly and to pick up as many passengers as possible. This led to problems such as high crash rates and discomfort for riders in the vehicle. However, the government is reluctant to change the status quo, because red minibuses are useful in soaking up extra demand for public transport during busy times like festivals (Dewolf, 2016).

Since the 1990s, policymakers in China have come to realize that building more infrastructure cannot solve the congestion problem. Therefore, public transport has been promoted by both national and local governments in cities. China introduced and implemented in Qingdao in August 2013 an innovative mode of PT systems, known as customized buses (CB), to provide advanced, personalized, flexible, and DRT services for specific clients, especially commuters. The most common CB type is a customized commuter bus, which carries commuters from their residential areas to work areas. The other CB provides pupils with a direct, safe and rapid transit service from their homes to schools. The CB system is organized and operated by local transit agencies and is heavily subsided by local governments. One good way to finance CB services is to have partners for the organizations, such as private transit agencies and community groups (Liu and Ceder, 2015).

In Japan, scheduled bus services are generally run by private companies that carry out all the marketing, planning, and operation of the buses. Since Japan deregulated its bus industry in 2002, transit agencies are forced to maintain non-commercial services through cross-subsidy of non-commercial routes. Like in the UK, this has led to a need for state-supported services where routes are not considered commercially viable. University of Tokyo researchers report that in some cases, these DRT services only require about half the subsidy of the fixed route community buses that they are replacing. However, even though the average total operation expenses of FTS are smaller than that of community buses, this has put pressure on public finances since the cost per passenger is still high (Wright et al., 2014; Yajima, Sakamoto& Kubota, 2013). The DRT (momo-cow) bus in Japan started on July 1, 2012, in the Ushimado area of Setouchi , Okayama, where there is no train station, and out of the 7,700 citizens, 2,400 of them are 65 years and older. The goal of the DRT service was to bring more convenience and accessibility to the elderly (“The Demand Responsive Transport (Momo-Cow) Bus in Japan,” 2019). Some DRT services were launched by volunteer organizations. More than 20 years ago, a volunteer group in Tokyo implemented a door-to-door service. This service was designed for volunteers to help the disabled when they get up from bed, move from their homes to the hospital, and apply for a medical examination. After waiting at the hospital until the medical examination was over, the volunteers helped them return home and settle into

their private room. This is a process known as "a transport with care." The taxi company, Medis, in Fukuoka practiced this transport service before the care insurance system started (Akiyama & Kim, 2005).

Three well-known flexible bus services, which are like DRT services in Australia, are Telebus in Melbourne, Roam Zone in Adelaide, and Flexibus in Canberra. In contrast to many services in North America, all three services are available to the public rather than being restricted to specific user groups. The operators of these vehicles include bus operators also running scheduled services, taxi operators (operating taxis), bus operators (operating taxis), and community transport operators using their own vehicles. The funding of these services varies from those funded under conventional bus contracts from the NSW Government, Home and Community Care (HACC)-funded community transport services, those funded by local authorities, and others funded by the private sector such as major employers (Daniels and Mulley, 2010). While subsidies for bus services are based on the kilometers a bus runs, it gives rise to barriers to the operation of flexible transport since predicting bus kilometers is difficult because of this on-demand service.

DRT can be very costly when uniquely focusing on mobility-impaired people, thus requiring public financial support (Laurent, 2017). One solution is to rely on volunteers to drive the vehicles. A case study in the Netherlands has shown that those volunteers are often retired themselves. Performing these services could help them maintain social contact. Therefore, volunteer-based DRT systems could be one way to save money as well as improve social cohesion in rural communities (Neven et al., 2015; Schotman, 2014). A summary of some examples of DRT are shown in Table 4.

3 ENGAGEMENT

3.1 INTRODUCTION

Many low-income or minority individuals and groups feel that they have no voice in society, that they are not heard even when they are asked for their opinions. This research utilized the methods of community-based participatory research (CBPR) to involve people who are often marginalized within planning processes. The study targeted the environmental justice (EJ) population who relied on public transit more than others because they are old, disabled or under financial restrictions, and usually transit captive. The research team formed a community advisory board (CAB) to inform the community engagement methods. Primarily, the CAB served as consulting partners of the research team. The CAB also helped inform community engagement strategies to gather input from EJ communities. For instance, they reviewed focus group and survey questions to ensure that they were culturally appropriate and covered all relevant content. They also helped the researchers to identify and recruit participants for focus groups and interviews. In addition, an online survey filled out by professionals explored the barriers to accessing transportation among transportation-disadvantaged populations.

The research team collected data using focus groups, in-depth, semi-structured interviews, and a complementary survey from communities. The target participants included individuals who experienced first/last mile transit access challenges (e.g., older adults, individuals with disabilities, lower-income single mothers, and individuals experiencing homelessness). Figure 3.1 displays the CBPR steps.

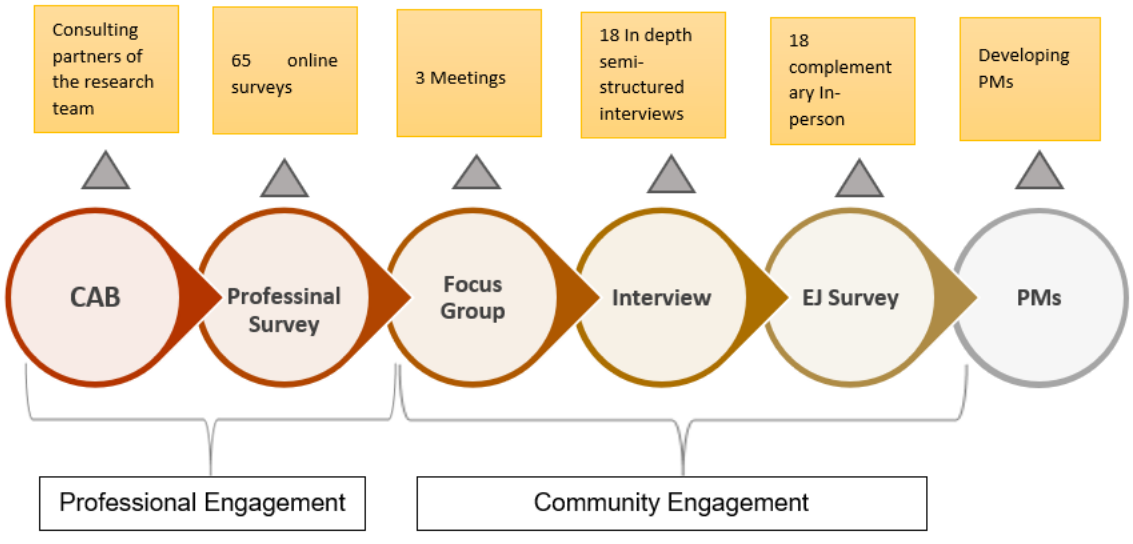


Figure 3.1: Community-Based Participatory Research Steps

3.2 PROFESSIONAL ENGAGEMENT

This component of the study sought input from different professionals to understand transit service gaps and investigate solutions. The professional engagement included the CAB and professionals' survey.

3.2.1 Community Advisory Board (CAB)

The research team assembled a Community Advisory Board (CAB) comprised of transportation experts, partners, and other providers of social services to EJ populations. This structure of the CAB aimed at discussing and exploring the new performance measures necessary to better assess transit service based on equity, health, and access to opportunities. First, an email was sent out to key stakeholders in the community to recruit members for this CAB. A snowball sample with key stakeholders recommending community professionals (e.g., council on governments, metropolitan planning organizations, city officials); social workers and direct practice workers (e.g., homeless shelters, senior center, nursing association); and transportation planners (e.g., local transit authority) was used to invite members to the CAB.

3.2.1.1 CAB Participants

A total of 14 key stakeholders volunteered to participate on the CAB(N = 14). Most CAB members were female (86%) and in the field of social work (64%). Participants worked within their areas of expertise across varying types of organizations, including government entities (e.g., Council on Governments (29%), non-profit agencies (64%), and one private agency (7%). Across the local areas where CAB members were employed, 57% had community public transportation access and 43% did not (see Figure 3.2).

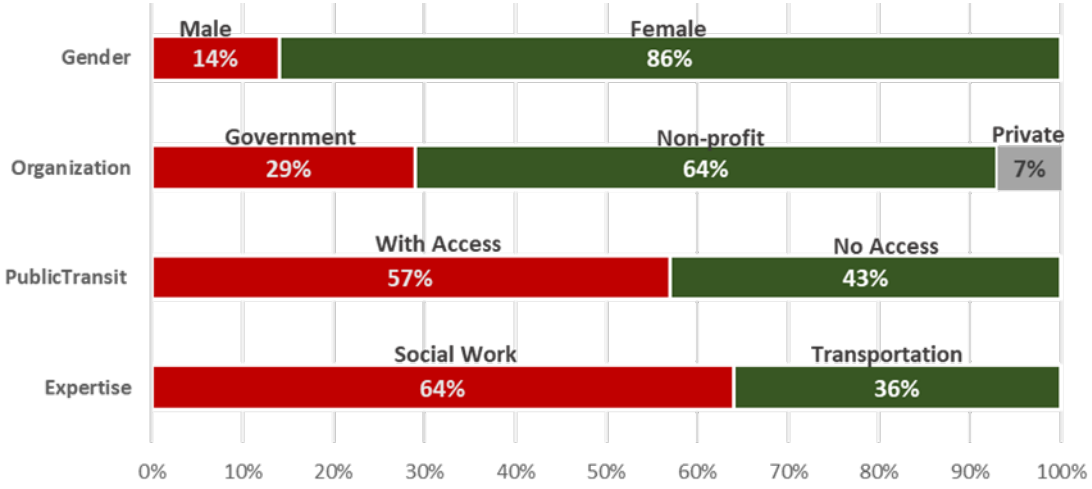


Figure 3.2: CAB Participants' Characteristics

3.2.1.2 CAB Procedure

Upon development of the CAB, and once each member confirmed their interest in participating, they were subsequently sent an email to select a time best for the first CAB meeting, held in May 2018. The purpose of this CAB was to guide research study exploring barriers to accessing transportation among transportation-disadvantaged populations; to serve as a consulting body on the issue of first/last mile issues and potential solutions; to review focus group and interview questions; and to assist in the identification and recruitment for focus groups and interviews. Meetings were held via an online web-based conference meeting room (Zoom) and lasted 45 to 60 minutes each. CAB participants logged into the virtual conference room via computer or telephone, from their chosen location. Meetings were guided by a PowerPoint presentation, which was used primarily to keep on task and cover all agenda content related to the larger study. Each meeting was held in an open-dialogue format that encouraged CAB members to provide ongoing, iterative feedback. Each meeting was audio recorded and uploaded into a secure cloud storage folder. Additionally, at least two research associates were present during each CAB meeting to take extensive notes.

3.2.1.3 CAB Results

Three subsequent CAB meetings took place in June, July, and October. The June CAB meeting shared the status of recruitment of focus groups and 20 in-depth, semi-structured interviews, and surveys from EJ communities. The CAB meeting that took place in July informed members about the focus groups that took place, as well as provided an update on survey distribution. The final CAB meeting, which took place in October, reported results of the data collection across the focus groups, in-depth interviews, and surveys. Figure 9 shows each CAB meeting agenda.

3.2.2 Professional Survey

The professional survey explored the barriers to accessing transportation among transportation-disadvantaged populations. The survey collected data from 65 participants (N=65) using survey questions about accessing transportation systems among the population that they serve.

3.2.2.1 Survey Participants

Participants were aged from 20 years old to 76 years old. Among them, 66% were female and 34% were male. Most of the participants were White (85%) and full-time employees (94%). Approximately 49% of participants had master’s degree and 11% had a PhD , law, or medical degree. Demographic information of survey participants is displayed in Table 3.1.

3.2.2.2 Survey Procedure

The surveys were distributed via email with a link to the Qualtrics-based survey (see Appendix-C). Once clicking on the link, participants were sent directly to the survey where

the first page was an informed consent statement. After reading it, those agreeing to participate selected “I consent” and were then advanced to the next screen automatically, which contained the survey. Participants completed the survey independently and anonymously. After answering demographic questions, participants were asked an open-ended question about addressing transportation in their job and then a series of questions about how transportation impacted the lives of EJ populations and the degree to which and how they tried to mitigate transportation barriers for EJ populations within the context of their work. The team downloaded the data from Qualtrics to analyze the results using descriptive statistical procedures.

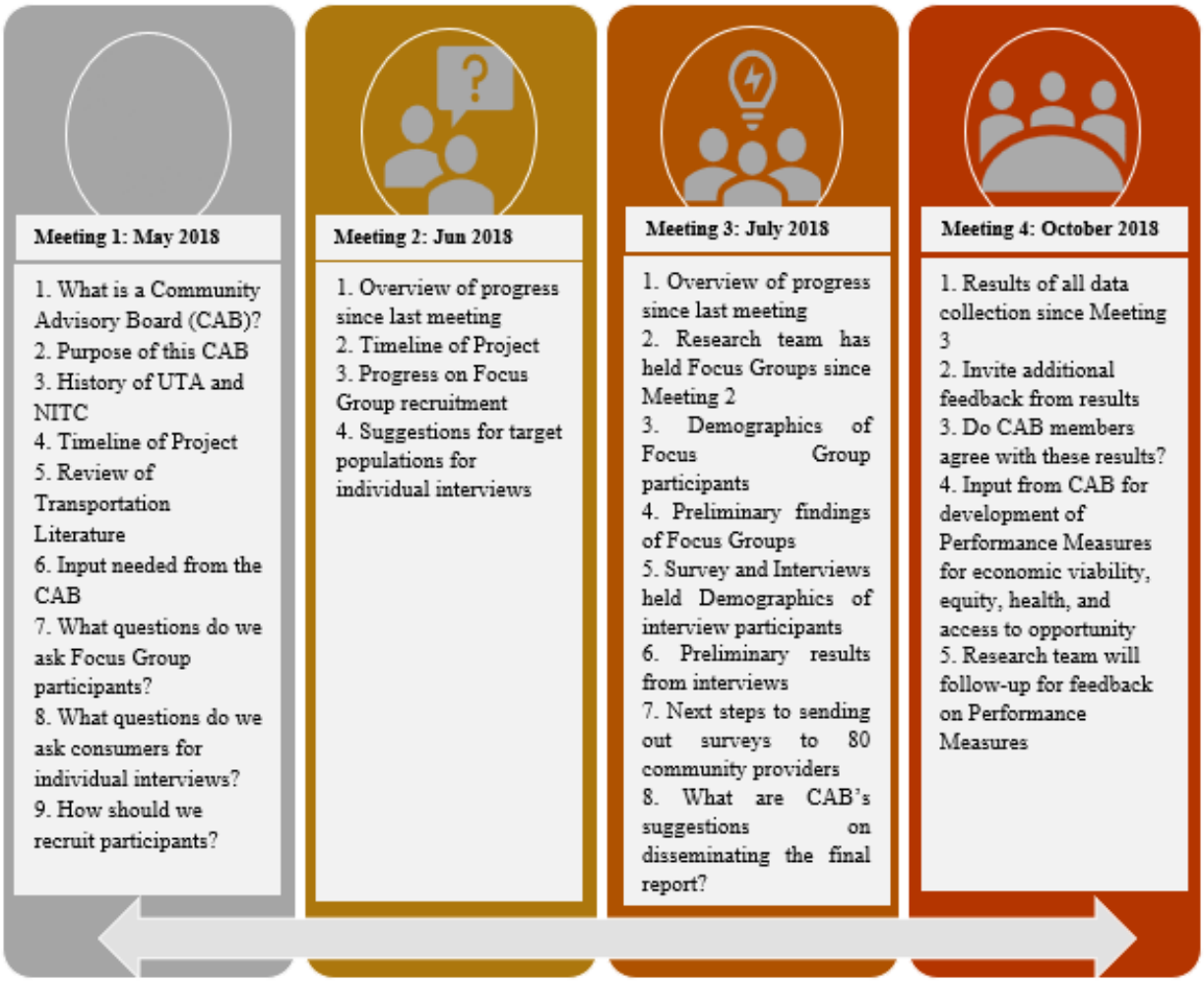


Figure 3.3: CAB Meetings Agenda

3.2.2.3 Survey Results

Sixty percent of the participants reported that transportation is frequently a problem for lower-income individuals, and 27% of participants mentioned that transportation is always a problem for lower-income individuals. Nearly 60% of participants reported that their organization provides transportation resources to lower-income individuals. Thirty-two percent of participants mentioned that their organization provides bus passes and 50%

mentioned other services. Most of the participants reported impacts on EJ populations. The poor connections provided by public transit and lack of other transportation options represent the largest concern (83%) of the survey respondents. FLM issues like long walking distances (70%) represent the next most significant barrier to low-income populations, which aligns closely with the large travel time generated by poor connections. Fifty-eight percent of the respondents believe cost represents a challenge for using public transit. Over half of the respondents identified waiting time as a significant barrier to public transit use for low-income populations. Almost half of the respondents identified knowing how to use the transit system and limited hours of operation as barriers, too. Car sharing received very limited support (9%) to serve as a significant transportation option for low-income populations; a few more respondents (19%) view car sharing as an occasional transportation solution for low-income populations. Ride hailing received somewhat stronger support (43%) as a tool for low-income populations. Table 3.2 displays the survey results.

Table 3.1: Survey Participants' Demographic Information

Variable	Percentage	Variable	Percentage
Gender		**Education**	
Female	66.2%	Completed some college	1.4%
Male	33.8%	Bachelor's degree	24.3%
Race		Completed some postgraduate	14.3%
White	85.9%	Master's degree	48.6%
Black	7.0%	PhD, Law, or Medical degree	11.4%
Indian/Alaska Native	1.4%	**Employment Status**	
Asian	2.8%	Employed (working 40 or more hours)	94.0%
Multiple Ethnicity	2.8%	Employed (working 39 or less hours)	6.0%

Table 3.2: Professional Survey Results

Question	Options	Percentage
1. What extent transportation is a problem for low income individuals	1. Always a problem	27.5%
	2. Frequently a problem	59.4%
	3. Occasionally a problem	13.0%
2. Organization provide transportation resources for low income individuals	1. Yes	60.9%
	2. No	26.1%
	3. N/A	13.0%
3. Provided transportation services affects use	1. Shuttle Service	17.5%
	2. Bus passes/vouchers	32.5%
	3. Other	50.0%
4. Cost of public transit affects use	1. Does not affect use	1.5%
	2. May affect use	38.5%
	3. Definitely affects use	58.5%
	4. Do not know	1.5%
5. Poor public transit connection affects use	1. Does not affect use	1.5%
	2. May affect use	13.8%
	3. Definitely affects use	83.1%
	4. Do not know	1.5%
6. Knowing how to ride the bus/train affects use	1. Does not affect use	6.2%
	2. May affect use	43.1%
	3. Definitely affects use	46.2%
	4. Do not know	4.6%
7. Limited hours of operation affect use	1. Does not affect use	1.5%
	2. May affect use	50.8%
	3. Definitely affects use	46.2%
	4. Do not know	1.5%
8. Safety affects use	1. Does not affect use	10.8%
	2. May affect use	55.4%
	3. Definitely affects use	30.8%
	4. Do not know	3.1%
9. Affordability affects use	1. Does not affect use	1.5%
	2. May affect use	43.1%
	3. Definitely affects use	53.8%
	4. Do not know	1.5%
10. Waiting time affects use	1. Does not affect use	3.1%
	2. May affect use	43.8%
	3. Definitely affects use	51.6%
	4. Do not know	1.6%
11. Lack of other transportation options affects use	1. Does not affect use	3.1%
	2. May affect use	13.8%
	3. Definitely affects use	83.1%
12. Walking distance affects use	1. Does not affect use	1.5%
	2. May affect use	21.2%
	3. Definitely affects use	69.7%
	4. Do not know	7.6%

13. How frequently do you recommend ride hailing services (Uber. Lyft, Via) for clients?	1.	Never	13.8%
	2.	Once/Twice	10.3%
	3.	Occasionally	32.8%
	4.	Often	22.4%
	5.	All the time	20.7%
14. How frequently do you recommend car sharing services (Zip car) for clients?	1.	Never	59.6%
	2.	Once/Twice	12.8%
	3.	Occasionally	19.1%
	4.	Often	4.3%
	5.	All the time	4.3%
15. Why don't you recommend car sharing services for clients?	1.	Too expensive for clients	26.5%
	2.	Clients feel uncomfortable	14.7%
	3.	Do not know about services	58.8%

3.3. COMMUNITY ENGAGEMENT

The study utilized a community-based participatory research (CBPR) strategy to identify emerging transportation needs for environmental justice (EJ) populations that focus on equity, health, and access to opportunity. The study conducts focus groups, interviews, and an online survey to identify the community's transportation needs.

3.3.1 Focus Groups

The research team conducted data in the form of focus groups, and a broad array of stakeholders regarding their perspectives on the first/last mile and its impact on transportation accessibility among EJ populations. The team conducted the focus groups via Zoom (virtual meetings). Professional/frontline workers' focus group questions have been added to this report as Appendix-A.

3.3.1.1 Focus Groups Participants

A total of three focus groups were held with stakeholders across the community. A total of 25 participants (N = 25) from a wide array of organizations shared their perspectives on the first/last mile issue and its impact on transportation accessibility among EJ populations. The focus group participants represented agencies including, but not limited to, Lyft Marketing, City of Mesquite, Freedom House, City of Arlington, MyRide, City of Dallas, and local independent school districts.

3.3.1.2 Focus Groups Procedure

Focus groups were professionally transcribed verbatim. Interview transcripts were then analyzed using Atlas.ti (7). A conventional content analysis approach was used to analyze the data (Hsieh & Shannon, 2005; Miles & Huberman, 1994). Individuals on the research team coded interview transcripts using an open coding approach. The team subsequently met together to create and collapse individual codes into larger family codes and to create

a codebook. Individual team members then coded each of the transcripts using the codebook. The themes presented below are the results of this final coding after reaching consensus on all themes. Direct quotes are representative and presented using a pseudonym to protect the anonymity of participants.

3.3.1.3 Focus Groups Results

A total of five themes emerged from the data: 1) Lack of transportation becomes a vicious cycle; 2) Bad for the individual, costly for the community; 3) Potential for linking communities and closing micro-gaps; 4) Stigma, and; 5) Constrained autonomy.

1) Lack of transportation becomes a vicious cycle

Across all of the focus groups, affordability played a key role in whether clients had access to reliable transportation. Transportation, in turn, was linked to money, job opportunities, educational pursuits, and overall financial stability. Many participants described the financial strain associated with accessing both public and private transportation. Though expressed in varying words, the sentiment remained consistent, that lack of transportation "becomes a vicious cycle." Generally speaking, participants felt that low socioeconomic status caused additional burden on individuals. Archie shares, "Financial burden leads to more hardship." Many felt that the lack of car ownership limited individuals' ability to obtain adequate employment or to pursue educational opportunities. Molly says, "[Clients] need the money to get the job, need the job to get the money." Livi further explains, "[Clients] need more education to get a job, can't get an education because they can't get to classes, can't pay for transportation because they don't have a job, can't get a job because they don't have education…and it continues."

While a lack of transportation represented one of the causes for lack of employment and higher education, it also presented concerns for those with employment. Inadequate or unreliable transportation was posited as a reason why some individuals missed work or were let go from their places of employment. Sammy explains, "They may have a car that's not really dependable and they may miss work because the car died. Then they may lose their job, it's kind of a vicious cycle for a certain stratum of our community." The idea of "vicious cycle" largely centered on employment, but respondents alluded to various outcomes that result from a lack of transportation. For example, Mae talks of the chain of events that resulted in a downward spiral for her client. She spoke about a lack of reliable transportation playing a large role in her client's pathway into homelessness:

"First, they lose their job because the car only runs half the time. Then, they move into the car. Then, they lose the car altogether because they can't make the payments. Then, they end up on the streets. All because they couldn't get to work."

2) Bad for the individual, costly for the community

In the first theme, vicious cycle, most of the rhetoric revolved around the implications of transportation disadvantage on individuals and families. For this theme, the participants tended to talk more about how, though transportation disadvantage is bad for individuals,

it is also costly for communities. Sarah described the need to generate political will in order to make substantial change in transportation infrastructure. She believed that in order to generate this political will, advocates should shift the conversation from individuals to communities, largely looking from an economic perspective. She shared, “They [policymakers and decision makers] don’t want to spend the money to provide transportation, but what they don’t realize is its costing us more in the long term.” Marshall elaborated, “I think it’s a costly situation for the community and for people, but we don’t think about big picture enough.” Ruben also agreed, “I really hope that Texas gets to the point where we can see the seriousness of it.”

3) Potential for linking communities and closing micro-gaps

Another theme that arose from the data is the clear gaps in services, particularly at city and county borders and where one agency’s jurisdiction ends and another’s begins. Participants refer to these gaps as micro-gaps and talk about creating interagency collaborations to link communities as a potential solution. Archie describes a micro-gap in the cities where the research team is housed: “Here in the state of Texas, what we are going to have to realize for us to move forward as far as transportation is concerned is the micro-gap. It makes no sense for the state to be this big and you cannot get from Fort Worth to Arlington on public transportation.” While agreement between participants that interagency collaborations and better linking of communities represent a potential way to close micro-gaps occurs, great variability in the perception of whether or not these collaborations already exist persists. Some argue that agencies almost never talk to one another. Allen talks of how he has tried to start a coalition across non-profits and faith-based agencies in his community, without much buy-in from local stakeholders. He says, “You know collaborations are you know, great and you know this probably…We need to gather together different groups and different charities and lump them in together to come up with solutions.” On the other hand, Sammy talks of how interested parties meet together frequently, but are limited in what they can do given funding restrictions. He shares:

“The mobility team is a tight community. We meet quarterly. We know the gaps, where people fall through the cracks, but funding mechanisms make it so difficult. We can’t help you because we’re funded by x. We have to drop you off here because they’re funded by y. It makes the whole system so inefficient.”

4) Stigma towards public transit riders

Stigma emerges as another theme throughout the focus groups. Individuals describe how public transportation users are often treated as less than their car-owning counterparts. This study reveals two major implications to this negative public perception. First, participants describe individuals internalizing this stigma, which may cause those experiencing transportation disadvantage to hide their disadvantage for fear of being treated as less than others. Lynn states, “The people that are having trouble getting places don’t necessarily want to reach out and tell people that they are having trouble.”

Many participants link the stigma with the vicious cycle because those in need do not want others to know about their plight until their condition deteriorates to the point where they must ask for assistance. Secondly, participants describe how the public perception toward public transit riders negatively impacted the ability to generate political will toward investing in transportation infrastructure. Gene articulates, “There’s a stigma when it comes to public transportation with certain cities. That stigma is low-income people ride transportation, so we don’t want it here.”

5) Constrained autonomy

Finally, participants talk of how a lack of reliable transportation options leaves vulnerable populations “just stuck.” They talk about how the lack of affordability, accessibility, and convenience constrains individuals’ autonomy.

Gene talks about the financial burden causing individuals to become socially isolated. He describes, “One barrier, especially for your seniors and your low-income, is going to be finance, affordability.” He continues, “Being left isolated and lonely at home is another disadvantage. Having no social life, just not being able to get out of the house.”

Sammy speaks of how (in)accessibility causes individuals to have trouble seeking healthcare in the community. He shares, “There’s a steep slope. Somebody operating a wheelchair has higher risk of tipping over or just not being able to go at all.” He continues, “If people do not have access…if they can’t access quality healthcare because of transportation, then they stay home and get sicker.” Sarah describes how accessibility encompasses physical health. She talks about accessibility in terms of cognitive health and of the barriers that individuals face attempting to access services in the community, “Many of our clients don’t have the cognitive ability to access or even call for those rides themselves.”

Lillian describes how the inconveniences of the status quo, particularly the need to schedule in advance and lack of readily available transit, limit participation in the community for many EJ populations. She posits that individuals would utilize more resources in the community if they had on-demand options for transportation. However, many of the current paratransit and ride options for individuals with disabilities limit individual autonomy, with strict scheduling and the need to plan even weeks ahead of time. She says, “Maybe they want to just come up that day and… those are the groups that we have the most trouble with.” Others describe long waits and indirect routes as another constraint on autonomy. Jill shares, “Car riders don’t have to ride for an hour and a half through 14 stops to get to where they need to get. Most people can’t do that.”

3.3.2 Interview and EJ Survey

The purpose of the interview was to improve the transportation system for individuals who may have difficulty accessing reliable transportation. Then, hearing about EJ population perspectives and insights into improving the transit system in the Dallas/Fort Worth

Metroplex helped to maximize access to transportation across the community. This report included the EJ population member interview questions as Appendix-B.

The EJ members completed a complementary survey in person at the time of their in-depth interviews. Surveys from EJ communities and a broad array of stakeholders collected their perspectives on the first/last mile and its impact on transportation accessibility among EJ populations. In addition, the survey results were triangulated with the qualitative data, so the survey results have been used to back up the focus group results. Table 7 shows the characteristics of interview participants and survey results. These interviews were conducted by social work researchers in July- August 2018.

3.3.2.1 Interview and EJ Survey Participants

A total of 18 interviews (N=18) were held with individuals across the community. The targeted participants from the EJ population included homebound older adults, unaccompanied homeless young adults, parents in emergency family shelters, and racial/ethnic minorities (see Table 3.3 and Figure 3.4). All EJ interviewees and survey participants were recruited through social service providers in North Texas. These interviews and the survey gathered individualized, in-depth perspectives on transportation obstacles experienced by community members.

Table 3.3: EJ Survey Results

Variable	N	%	Variable	N	%
Gender			**Place of Residence (last 30 days)**		
Female	14	77.8	Own home	8	44.4
Male	4	22.2	Living with family/friends	4	22.2
Marital/Relationship Status			Hotel/motel	1	5.6
Single, never married	6	33.3	Emergency shelter	1	5.6
Married	3	16.7	Transitional housing	2	11.1
Living with a partner	1	5.6	Permanent supportive housing	2	11.1
Divorced	4	22.2	**Difficulty in Paying for Basic Needs**		
Separated	4	22.2	Never difficult	1	5.6
Ethnicity			Occasionally difficult	5	27.8
Hispanic, Latino, or Spanish origin	8	44.4	Often difficult	6	33.3
Race			Always difficult	6	33.3
White	12	66.7	**Social Service Support Received**		
Black or African American	2	11.1	SNAP (supplemental nutrition assistance program)	8	44.4
Multiple Ethnicity	3	16.7	TANF (Temporary Assistance to Needy Families)	1	5.6
Others	1	5.6	SSI (Supplemental Security Income)	2	11.1
Parental Status			SS (Social Security)	7	38.9
Have Children	16	88.9	**Disability**		
Does not have children	2	11.1	With Disability	7	38.9
Employment Status			**Require using special equipment**		
40+ hours per week	2	11.1	requiring assistive device (wheelchair, cane)	5	27.8
Less than 40 hours per week	2	11.1	**Primary Mode of Transportation**		
Not employed and looking for work	5	27.8	Personal automobile	6	33.3
Student	1	5.6	Friend, relative, neighbor	5	27.8
Homemaker	1	5.6	Public transportation	5	27.8
Retired	2	11.1	Medicaid transportation	2	11.1
Disabled and unable to work	3	16.7	**Highest Level of Education**		
Work odd jobs off and on	2	11.1	Some high school	3	16.7
Experienced homelessness			High school graduate	5	27.8
homelessness before age of 18	2	11.1	Completed some college	8	44.4
Experienced Runaway			Associates degree	1	5.6
Runaway before age of 18	5	27.8	Bachelor's degree	1	5.6

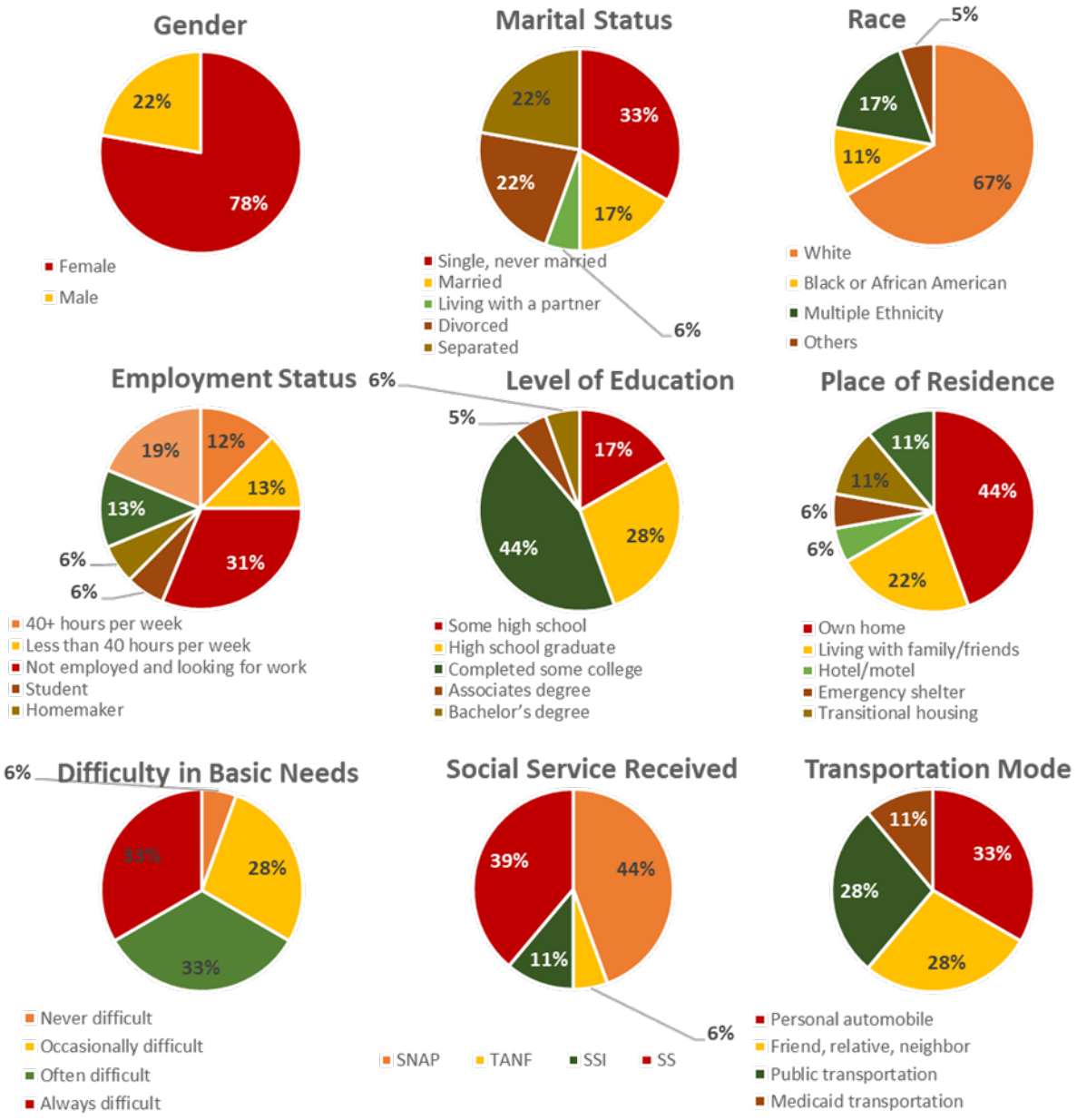


Figure 3.4: Demographic Characteristics of EJ Survey Participants

3.2.3.2 Interview and Analysis Procedure

The team collected data in the form of individual in-depth interviews, which lasted approximately one hour. All participants signed an informed consent form prior to beginning the interview and all received $5 gift cards as compensation for their time. All interviews were recorded digitally, and audio files were subsequently transcribed. Two research team members independently coded the written transcripts using direct content analysis (Elo & Kyngas, 2008) followed by axial and iterative coding (Strauss & Corbin, 1998) to condense codes into themes. The team members used healthcare access,

healthcare utilization, and first/last mile accessibility as sensitizing themes throughout the analysis (Blumer, 1969). The first author reviewed resultant themes and then met with the second analyst to reach consensus. Rigor criteria were maintained throughout the study including a paper audit trail, peer-debriefing sessions, deviant cases analysis (Creswell, 2007; Lincoln, 1995; Lincoln & Guba, 1990), and triangulation through the use of multiple data analysts (Patton, 1999). As a final check, the team presented preliminary results to the CAB for verification.

3.2.3.3 Interview Themes

A total of nine themes emerged from the EJ interviews. The themes included: 1) Accessibility, 2) Affordability, 3) Disproportionately Impacts Vulnerable Populations, 4) Incentives/ Encouragement to Ride Public Transportation, 5) Limited Services, 6) Missed Opportunities, 7) Built Environment, 8) Safety, and 9) Inconvenience. A number of these emergent themes had subthemes, which are expanded on in the results below.

1) Accessibility

Participants shared that accessibility to services within the community represented a challenge, due to a lack of transportation access. One participant stated, “Well, like trains here, they got a lot of trains that covers all states, but we don't have any public transportation practically.” Another, similarly, shared: “Here we don't have anything else. So, you take the bus or on foot.” One participant stated: “Now, I don't have a car, and I don't have money, or didn't know a bus station, or transportation next to me in this area.” While there may not be public transportation access, or accessibility, one participant shared their solution in asking others for help, “I always have to ask people to pick me up or drop me off, which is fine. Most of my co-workers are really nice and they don't mind too much, but I feel bad asking it. I don't know. I hate asking for help, number one.”

2) Affordability

The affordability theme emerged from the interviews with EJ community members. Two sub-themes appeared nested within this theme: public and private. Participants shared issues and concerns with affordability of both public transportation options, as well as private transportation.

Public Transportation Affordability: One participant shared: “Now, they make everybody pay. I can afford it, but there's a lot of people in this building that can't use a bus anymore, because they cannot afford a dollar one way and a dollar back. So, that's a bad bill for some people.” Similarly, another stated that public transportation shouldn’t have an associated cost or fee: “It’s just the fact that you have to pay for public transportation, it defeats the purpose of it being public transportation because most people that take public transportation are doing it because they don't have funds to buy a car or they don't have a car or lack of money to buy maybe a Uber or give somebody some gas money. I feel like it defeats the purpose to ride public transportation when

they're just going to charge you a fee to ride it anyway." A few participants discussed the fees associated with use, with one sharing: "I didn't realize it was each way. That's a $9.00 round trip. That's if you only have one stop. That's crazy." Another stated: "I don't always have $4 or $9, $10 to give MIT." Lastly, a participant shared, "And if you have a wheelchair, you have to bring that chair up by yourself. They're not going to go to the door and get you. If you want that, now, you're going to pay extra. So it comes like $7 and change. It's like $12.50. Because they do the whole county."

Private Transportation Affordability: A number of participants shared their experiences with private transportation, such as ride-sharing options like Uber, Lyft, and taxis. One participant stated: "The cost factor and the convenience factor is not really, well, not within my budget." Another shared: "When it comes to Lyft or Uber, it's expensive and sometimes people don't have the money, the resources, to be able to pay for Uber or Lyft." Similarly, participants shared, "I only take it if I really need to, can't find a ride, can't walk there, can't find any other way to get there. Uber does get pricey sometimes," and "Yeah and my delivery time, so I had to take Uber. My mom paid it for me because I don't have a credit card, so she was nice enough and paid for me but that's the only time I've really ever used it because I don't own a credit card." For many participants, not having a credit card to use, which was required for the app, restricted private transportation use. One participant stated: "Because I really don't have money or credit card to use them" and another shared: "Yeah. It limits who can use it, but you got to have the card on file and a smartphone and the app and all that."

3) Disproportionately Impacts Vulnerable Populations

Participants, in interviews, shared that the lack of transportation opportunities and options disproportionately impacts vulnerable populations. One participant shared: "I can't walk long distances, so that's the reason I have a chair. My legs are real bad, and pain in my feet I can't walk long distances. I can walk, but I can't walk long distances. So, that's the reason I have a chair, and I have to depend on my chair." Another expressed that transportation options failed to consider older adults or persons with low-income, sharing: "Not elderly-friendly or ... Needs more organization. Needs to think more about the people with low income that don't have any transportation at the house, and they need to go their medical appointments and need to spend time waiting for somebody to get a ride or the family member takes him to their hospital." Students were also identified as vulnerable populations, where one participant stated: "think it would be fantastic if they would ever put transportation, I think for a lot of us, even for the students, for the kids that go to school, or even for their parents or the elderly that don't have a car." Lastly, one participant stated: "Some places that it takes you to, especially for a handicapped person, that if you're on the regular bus, they can drop you off maybe two blocks away from where your appointment is with your doctor or where you need to go."

4) Incentives/Encouragement to Ride Public Transportation

Participants shared that they wished incentives and encouragement to ride public transportation existed. Changes such as these might encourage more utilization of public transportation options. One participant stated, “[They] Would like better hours here. We only have transportation once every hour. I would like better hours of transportation, but according to them, they have to pay, and the bus drivers they can't afford to run this route out here more than once an hour.” Another participant shared that they think improvements can be made: “Oh well, yeah, they can improve it a lot by maybe moving a bus stop a little bit closer to where they are, okay?” or instructing the passenger, "Okay, here's what we're going to do. We make this loop around, and then we come on the other side, which could be closer to where your doctor's office is.” Similarly, an increase in service hours/days would help encourage ridership, where one participant stated: “But that would be very helpful. And again, having a route out here on Sunday would be good. Having it run a little later would be good. I mean, not all of us seniors go to bed at 6:00 at night. I mean, some of us stay up late.” Another stated, “If it was free, I would be more inclined to ride it.”

Another participant mentioned an improvement in stops and increase in buses: “Probably just better stops. And if it was ... I think we need more buses. I just think they don't have enough buses to go all the way around to get people with enough amount of... People just wait for so long for buses. It just makes it ... it’s cheap enough. I think that's fine, but it's definitely not enough buses.” Similarly, a participant stated: “Just more accessible. If there were bus stops around the busy areas. Trains that didn't just go to one spot, that went all over the place that would be great. And I guess the schedules, like if there were more buses.” Lastly, one participant noted accessibility to the nearby stops would help: “Well like I said, if they put bus stops in front of apartment complexes or in front of major stores or landmarks that people are around, then it would be easy to get to the places that, you know, you have to get to by car. Like, you can't really walk. So just having accessible bus stops in local areas would be great.”

5) Limited Service

Another theme that emerged from the EJ interview data was “Limited Service.” Participants shared that limited-service opportunities to transportation presented a challenge to them. Two sub-themes emerged within this theme, Geographic Limitations and Time Restrictions.

Geographic Limitations: One participant shared that due to geographic limitations, they are at-risk of getting stuck. This participant stated, “Right. I could maybe take Handitran to the YMCA, let's say. Can't get home, sometimes it happens, I can't get home. I'll take Via home. But it doesn't come here. Stuck.” Another participant similarly shared: “I’ve used Via because it's cheap, but the problem is it doesn't go everywhere in Arlington. Like, there's zones. And it won't go up where the Parks Mall is and things like that.”

Time Restrictions: Time restrictions also represented a challenge for EJ participants. One individual shared, “I basically would love them to have a Sunday run out here. I mean, they don't have to have a full day, just a partial day like from 9:00 to 3:00, so I can get out of here and go to church, cause there's no church close by that I can go to.” Similarly, another participant stated: “Yeah, but you've got to do it early enough. I can't do it like two days from today. Today is Wednesday, I can't change Friday's schedule. I'd be pushing it. I'd be like, forget it. That's where the difficulty comes in.” In conjunction with the geographic limitations, time was an issue. One individual stated, “If want to go anywhere on Friday I have to do it today. I can't do it Monday; I have to do it Wednesday. Now here, because I live so far south, I'm not up here in the hub, that old 13 area, zip code, it's very difficult. Very difficult.” Another shared: “It has a lot to do with time management, because the train gets there, or the bus, and it's gone if you're not there on time.” Lastly, a participant reported: “Yeah because there was not available all the time. Sometimes you need to go and do, and time will be after one hour. It's very hard to do. This is a problem.”

6) Missed Opportunities

Missed opportunities represented an emergent theme among study participants, where individuals shared that they missed out on activities due to their lack of transportation services and options. One participant discussed their inability to go to a doctor appointment, sharing: “told him bring me back here and drop me off. Another one would pick me up. And came on back here. I knew I had to make that doctor's appointment. I could not miss it. I got to my chair to go to [inaudible 00:03:03], because I can pick up the bus there, and I can get to [inaudible 00:03:06] if I have to. And I got as far as [inaudible 00:03:08], and I said, ‘No, I can't do it.’” Another individual had issues with doctor appointments, stating: “Mm-hmm (affirmative). I had a customer. I was out, they left me out there so long and the doctor's office was getting ready to close. Everybody was leaving and it was getting dark outside and I'm like, ‘What the hell?’” Similarly, another participant stated: “That's why I have to slow down in the middle of the year, going back and forth to my doctor’s appointment because I'm going to run out of rides.” This challenge occurred for many individuals. Lastly, another stated that they just had to cancel their appointment, stating: “Yeah, because I had a doctor appointment I didn't even go to. I just called them and told them I had to get my ride squared away.”

Participants also discussed their inability to participate in social activities, like movies, stating: “And if you want to go someplace like a movie or something, you got to do it during the daytime when it's 109 degrees outside. You can't do it, so that there cuts you from being able to see the movie, because you can't get out, because you don't want to go out there in hot time, because the bus doesn't stop by the movie house. It stops five blocks away from the movie house.” Another individual stated, “I don't know what else about ... I just wish they would bring something. Even if it's a paratransit. If they could give us a little more on Sunday where people want to go and visit someone's house to have a bar-b-que. Or if it's a birthday party or wedding, I can't go. Unless they make a

prearrangement with someone or take Uber and "shmuber," Lyft." Residents also missed shopping opportunities due to transportation challenges, "But I would love to see public Trans because if I decide yesterday morning or yesterday evening, I wanted to go to Parks Mall to get something, I can't. Now, I can stand on the corner of Cooper, which is a major road. Cooper does go to Parks Mall if I'm not mistaken. I can't do it. I got to prearrange it all. I can't do it the night before."

7) Built Environment

Participants shared their concerns about the feasibility of using route-based transportation alternatives, like a bus. A couple of participants shared that feature of the built environment within their communities limited access these transportation options. One participant shared, "So that's the other thing, if they do ... Well, there's a lot [inaudible 00:18:14], but the streets here, how could a bus go up and down some of those streets? There's no shoulder. No leeway, nothing. You go on Bowen, I have a friend that lives off of it, I tell her, Joan, how do you walk on this street? It's dangerous. The sidewalk is here, and the cars are right there." Another participant stated, "Nothing. It's dangerous. How would you bring a bus there? You can't. You would hold up the traffic. It's only two lanes this way and two lanes the opposite way. So, I don't know how."

8) Safety and Security

Safety and security also emerged as a theme from the participants in this study. Getting to transportation and using public transportation represented the two sub-themes nested within the safety and security theme.

Getting to Transportation: One participant shared their experience getting to transportation services and her safety and security concerns, sharing: "Yes, I had a real bad experience with MITS. I was supposed to go to the doctor, and MITS drove up. And, he said, 'Are you Mary?' And, I said, 'Yes, sir, I am.' And it was just one that where you just get in. And, we started out, and I said, 'Where in the ... I wonder where this man's going.' Well, they pick up other people too, so I thought maybe he was going to pick up somebody. We got through a shopping center, and he's getting ready to unhook my ... I said, 'Wait a minute.' I said, 'I've got to go to the doctor.' And he said, 'Oh, I picked up the wrong person! Oh my!'" Another participant shared that due to the location of drop off and pick up, particularly from their homes, the ride was not always secure, "Not having the proper places to let you off closer to your location, like our location here where I live, they stop at 7:30. So if you want to go out, see fireworks or go to the Bass Hall or just go out to dinner and not have to worry about rushing back, you have to plan everything to be back home by 7:30, because if not, then two of you are walking or using your power chair to get home. It's scary at times."

The participants in this study faced significant need and might have had compounding health issues, which seemed common among EJ populations. One participant stated he was at risk for overheating, "So, I had to wait about another hour for it, which brings me to this past Monday. I went down to the Fort Worth Food Bank on Galvez Street, took the

bus down there, had no trouble getting there on the bus. Getting there went perfect, went up through the line and got my commodities, then I come back out, just missed the bus. So, I'm over in the bus stop, which has a top, a roof, but the sun was just coming straight into it, because it hadn't quite raised up enough yet. And so, I was sitting there in the heat waiting and waiting. And that day, it would have been a lot better if they had a bus every 30 minutes going through there, because I got kind of weak." He also stated, "Then on the real ice-cold days when the wind's blowing and the snow's coming down and it's like 32 degrees or below out there, and you're sitting at that bus stop. And the bus driver comes up and says, 'I can't take you. I already got two wheelchairs on the bus.' I called MITS, and I sat there, and I was freezing." Another participant with children shared similar concerns, stating: "Because you are going back to the thing about weather, you know, if you have kids it makes it difficult to wait around a long time. There is not a bathroom, or you don't need to deal with stuff like that."

Another participant shared their experience waiting on public transportation, stating "Everybody leaving out of there. They locking up and I'm standing on the outside like, 'Hey, I'm black.' Right. Police come by, he thinks I'm trying to get in and rob the place. Right. You were just waiting on a ride." Similarly, participants did not feel safe while waiting on public transportation, where another individual shared: "So, a boy came up to me and was telling me with explicit words, 'Why you are asking me something?' It just scared me so much. I was scared. I can take the train or the bus all day long, but that scared me. It just kind of put me back into reality, like you can't be off guard even here. So that's why."

While Using Public Transportation: Safety also represented an emergent theme for individuals while using public transportation options. For one older adult participant who uses a motorized scooter, "It made me nervous, because I thought she had hooked it up, but she was running behind schedule, didn't know the route, bypassed the location where I was at, had to turn around and come back and pick me up, then was rushing, rushing, rushing me. She didn't hook the back up on it, and she was going down the street real fast, and I think she was [a] two-footer, because she was going fast, and all of a sudden, the bus stopped, and my chair moved forward, kind of tipped forward. I almost fell out of the chair. I was in the back part there ..." Another participant shared their experiences of witnessing fights on the bus, "The bus driver didn't stop them, the bus. He didn't do nothing about it. I think he can do it, but. But those people they start fighting, fighting, and fighting." Other participants were just too scared to use public transportation; they said, "I took him on the train before, actually. I don't think I've taken him on a bus yet. I'm too scared to take him on a bus." Another stated: "you know it was always just so crowded and everything. And another thing though, sometimes you don't know the, I thought it might be dangerous, okay?"

9) Inconvenience

Inconvenience emerged as the final theme from the EJ interviews. The two sub-themes within inconvenience included: routes, wait times, connections and planning ahead.

Routes, Wait Times, Connections: Participants shared that a portion of their time utilizing public transportation included extensive wait times at bus stops. One participant stated, “Well, I didn't like standing at the bus stop with no cover like they had back then. They didn't have covered bus stops in the rain. That was no fun when it was wind blowing when it was 22 degrees outside. I'm not going to say that was an enjoyable thing and most bus stops, and still many in Dallas from what I've seen, still don't have seating or covered space except a sign for the bus stop.” Another shared, “No. Yes. So, also it would take way too long. It just takes too long. I don't have patience.” Another shared that in addition to the wait times, connections were challenging to complete, especially based on scheduling, where one participant stated, “Well, they're good sometimes, like when you schedule your ride three days ahead of time, 72 hours. They're good and sometimes they pick you up 45 minutes before it's time for your appointment. You get there early. It's okay, but if you wait and call them when you need a ride home, it takes them like an hour, two hours to come back and pick you up. So, when you schedule it I have to ask my doctor about how long will I be there so I can schedule my ride time home and I don't have to wait about an hour or two hours until they get to do what they got to do...” These long wait times and challenging connections made transit hard for participants to use, where another individual said, “it was a couple of years ago, the bus schedules were pretty far apart, and if you missed one bus, you'd be late to wherever you were going. So, you had to make sure you were on time and did not miss that bus. So, it was pretty hard to use and difficult.” Lastly, another participant said, “You know, because you have to wait about 40 minutes to an hour for a bus to come and so you have to be there. If you're there late, you know, you have to wait an hour or two for it to come back again and that would probably be it.”

In addition to the long wait times at the bus stop, sometimes buses would not show up on schedule. For example, one participant shared, “So, I was sitting there waiting for a bus, the MITS bus, and the MITS bus never showed up.” Another participant had a similar issue, sharing: “No. They didn't tell me what happened, but the lady talked to me and talked to the driver. The driver was steady lying like, “I'm right around the corner.” No, she's not right around the corner because I've been standing outside for two hours.” Even the public transportation drivers, at times, encouraged riders to wait even longer, where one participant shared: “The time, yeah. But sometimes if I went someplace and I want to go to home, the conductor said the bus will come after one hour. I don't know what I should do at this point.”

The long walking routes to the bus stops or for making connections represented another challenge for participants. One participant said that it wasn’t a problem because they walk all the time, sharing: “It's all walking. But it doesn't matter to me because I just walk all the time. Only when I'm in a hurry to come here because I need to be on time here.” However, not all participants shared this sentiment: “Yeah, as long as they don't put it that far away. Yeah, because two miles is kind of far to walk, especially people who have disabilities or people with wheelchairs, it's kind of hard for them.” Similarly, another individual expressed, “And if they're dropping you off three blocks away or four blocks away from

the stop, you're going to have to stop. Well, I know at my age, I would have to stop almost every block and catch my breath. Well, on the maps that they bring up on Google for the bus system, they tell you, ‘Okay, we're going to drop you off here, and you're going to have to walk like 15 minutes to your stop where you need to go.’” Finally, with disjointed transportation systems, the required connections for individuals to get across town were especially challenging. One individual shared, “Because in other places, what makes it easier to use it, is when there is a lot of buses one after another. You know what I mean? So, if you miss a bus, you will find another one that is coming in five minutes or less. But here it is not like that, if you miss a bus, it is going to be 45 minutes. If I want to take a bus to the other side of Dallas, it is going to take about two and a half hours.”

Planning Ahead: Planning ahead formed the final sub-theme within the larger theme of inconvenience. Participants within the community reported that they had to plan ahead extensively in order to achieve their trips for the day while utilizing public transportation. One individual said that this planning became a part of their daily life, stating: “No public transportation system is going to be that convenient, so you have to put it in your mind that plan that you're going to have some waiting. I lived with it back in the '70s in Dallas. I learned how to plan my days’ time to allow for transportation. It became a normal part of life.” Another shared similarly, “Yes. You have to plan ahead to know that you're going to connect with a bus.” The mother of a child also has to plan ahead when buying items for her family, sharing: “Yeah. Yeah. Exactly because I just have to plan everything out more than I would have if I had a car. Otherwise, I'd be like, ’Oh, we need diapers, we'll just go to store and get diapers.’ But now, I'm like, ’Okay, we've got five diapers left, I've got to get them before tomorrow’” Some participants just got into a routine of managing their time accordingly, where an individual stated, “Dramatically, because I wouldn't have to worry about myself driving over to the station. But I'd have to time management and make sure to be there, be ready when they leave.”

For those riders using Handitran, or other ADA paratransit services for older adults and persons with disabilities, these trips had to be pre-arranged; one individual shared, “Everything I do. Being I have that chapter meeting ... so when we have any kind of event or meeting, I always give it out 14 days in advance and I tell those alert Handitran consumers, start calling your scheduler today, Monday, blah, blah, blah. I give all that information to those that use Handitran. Because otherwise they'd be stuck with nothing. You can get a ride there, but you can't get a ride home. You can get a ride home, but I can't get a ride there.” Another stated: “can't do that with Handitran. It should be prearranged. Now, I've always done it 14 days out so I can guarantee the trip.”

4 PERFORMANCE MEASURES

4.1 INTRODUCTION

Numerous transportation agencies use transportation system performance measures (PMs) to introduce their policy, planning, and programming activities (Pickrell & Neumann, 2001). Also, many agencies have begun to discover the use of PMs regarding efficient resource allocation in planning and programming process (Cambridge Systematics, Inc., 2000). Measuring the performance of a transit system represents the first step toward efficient and proactive management (Bertini & El-Geneidy, 2003). This chapter reviews PMs in public transit agencies, for transit management, planning and operations. This section also reviews transportation equity factors utilized by either researchers or transit agencies to determine their usefulness in assessing resident needs and disparities between populations. This initial review of current PMs provides a foundation for identifying the current PMs that align with the needs identified in Chapter 3 and the needs that still require measures, The alignment of public transit system PMs with the needs of transportation-disadvantaged populations provides a method for transit agencies to assess the objective of providing effective transportation to all rather than congestion mitigation.

4.2 PUBLIC TRANSIT PMs

Public transit agencies develop and use PMs to inform planning, operations, and management decisions. “A performance measure is a numeric description of a system and the results of that system” (Performance Measure Guide, 2009). Many agencies define performance measures to pursue program and project outcome and to enhance internal operations (Pickrell & Neumann, 2001). Picking the ‘‘right’’ measures that align with agency objectives plays a key role in the usage of PMs to impact agency decisions, specifically policy and resource allocation decisions, and requires more than the measures themselves. Performance-based planning must be merged into an agency’s ongoing planning, management, and decision-making processes to create a comprehensive integrated data-driven performance improvement system (Cambridge Systematics, 2000). The performance measures assist decision makers in setting priorities, generating financial resources, and allocating funds. They also help to assess needs, evaluate system performance and simplify communicating with customers and other stakeholders. To be effective, performance measures need to be linked to the goals and objectives that guide transportation decisions. The goals and objectives of transportation systems should inherently represent an expression of the stakeholders affected by the system. This includes not only the providers of transportation but also the customers and the communities that house the transportation infrastructure. Therefore, performance measures must include metrics that address the interests of all stakeholders (Falcocchio, 2004). In addition, transportation system performance measures and indicators provide decision makers with a sense of whether their decisions improve transportation system performance or organizational productivity. By monitoring such

indicators, other officials, legislators, and the public can also follow the continuing efforts of transportation agencies to improve the performance of the transportation system (FHWA, 2004). An effective catalog of performance measures should include those developed by decision makers using a top-down approach and the users and stakeholders using a bottom-up approach.

4.2.1 Previous Works by Agencies

Transit agencies define their performance measures in transportation manuals and operations, planning, and strategic, reports. Transit agencies usually seek to provide public transportation for people of a region or a city and reduce congestion in the same locations. This study randomly investigates 20 of these transit agencies from 15 different states. After reviewing the PMs used by these agencies, the team categorized them into seven major groups: cost effectiveness/efficiency, customer focus/community, environmental, operations, reliability, safety and security and service quality. Table 4.1 shows some of the PM categories considered by a few of these transit agencies.

Table 4.1: Examples of PM Categories Considered by Transit Agencies

Organization	PMs	Organization	PMs
The Fairfield And Suisun (California) Transit (FAST) 2016	• Service • Ridership • Customer Focus • Financial/Cost Efficiency • Community/Environment • Coordination of Public Transit	**Orange Beach, AL Transit Feasibility Study (BRATS) 2017**	• Demand • Supply • Budget • Balance • Effectiveness
The Memphis Area Transit Authority (Mata) 2017	• Ridership /Efficiency • Reliability/Quality • Customer Focus • Safety/Security	**Nashville, Tennessee Transit Agency**	• Service Effectiveness • Cost Effectiveness
The 2009 Transit Plan (Colorado)	• Breckenridge Transit - Free rides • Operating Effectiveness • Financial Efficiency	**The Pasadena, California Travel Agency**	• Ridership • Passengers Per Hour
The District Department of Transportation 2017	• On-Time Performance • Boarding Per Revenue Hour • Operating Cost Per Revenue Hour • Subsidy Per Rider • Bus Stops Per Mile • Customer Complaints Per 10,000 Passengers • Preventable Crashes Per 10,000 Revenue Miles	**Greenville, NC Transit Agency**	• Ridership • Cost Per Passenger Trip • Cost Per Mile • Passenger Per • Revenue Hour • Passenger Per Mile • Fare Box Recovery Ratio

Current public transit PMs do not emphasize important issues for EJ populations like access (e.g., employment, healthcare, healthy food, green space, and social) because transit agencies typically focus on system management and efficiency and attracting choice riders. Table 4.2 identifies the percentage of the transit agencies using performance measures from each category. Most agencies use cost effectiveness/efficiency and operations performance measures, but no other categories see consistent adoption. With fewer than 50% of the transit agencies using each of the different categories, most of the agencies appear to rely primarily on PMs connected to Federal Transit Administration (FTA) reporting requirements and fail to broaden their self-assessment. The transit agencies lack consensus PMs to measure accessibility, connectivity/mobility, and service quality.

Table 4.2: Agencies Using Different PMs Categories

PM Category	Percentage of agencies consider this PM Category
Cost Effectiveness/Efficiency	72%
Customer Focus/Community	39%
Environmental	17%
Operations	72%
Reliability	28%
Safety and Security	44%
Service Quality	39%

Table 4.3 shows even greater inconsistency in the adoption of specific PMs by transit agencies; this table shows all performance measures used by 10% or more of the sampled transit agencies. All of the cost effectiveness/efficiency measures fit with the FTA-required data and the PMs reported in the National Transit Database. The operational PMs related to service coverage represent the most frequently adopted PMs with 42% of agencies assessing passenger miles per trip and vehicle miles. “Complaints” represents the only customer or community-related PM with “frequent” (14%) usage. The safety PMs emphasize safety related to crashes rather than passenger security; this may be caused by many agencies not operating a dedicated police or security force. Without this organizational component, most transit agencies may not have the ability to directly influence security in a meaningful way even though it may impact ridership. The lack of community-based PMs makes assessing the equity of the transit system or the accessibility for different neighborhoods appear unimportant to most transit agencies. Unfortunately, this does not coincide with the themes identified by the communities in Chapter 4; the next section proposes new PMs that align with the communities’ recommendations.

Table 4.3: Most Frequently Used Performance Measures

PM Category	PM	Percentage of Adoption
Cost Effectiveness/Efficiency	cost efficiency	10%
	cost per hour	13%
	cost per mile	13%
	cost per passenger-trip	23%
	fare recovery	10%
Customer focus/Community	complaints	14%
Operations (Service Coverage)	passenger miles/trip	42%
	vehicle miles	42%
Operations (Service Hour)	travel time	22%
	dwell time	13%
	hours of service	17%
	passengers per hour	17%
	vehicle hours	17%
Safety and Security	crashes per 1000 miles	19%
	crash rate	25%

Appendix D summarizes some SOP public transit PMs that are derived from selective national transit agencies reports and manuals. Current public transit PMs mostly focus on system management and efficiency and attracting choice riders. However, some recent efforts by transit agencies seek to address transportation justice more effectively.

4.3 TRANSPORTATION EQUITY

Transportation equity has received greater attention in the past decade. While a rich body of literature describes the definitions of transportation equity and justice (Martens & Golub, 2014), comparatively less work specializes on analytical approaches, either quantitative or qualitative using real-word examples.

Scholars have discussed the issue of varied levels of access to opportunity, and often suggest that accessibility represents the best framework for considering equity in transportation. Mavoa et al. (2012) categorizes accessibility measures in transit area into three categories: (1) access to transit stops, (2) duration of public transit journeys, and (3) access to destinations via public transit.

Among transit users the EJ population, which includes older adults; racial and ethnic minorities; persons of low-income with children; persons with limited English proficiency; persons with disabilities; female heads of households;and zero-car households (Federal Highway Administration, 2017), is more likely to rely on public transportation on a regular basis than others (Anderson, 2016). For EJ cases, promising transportation is one of the primary barriers that blocks low-income individuals' paths out of poverty (Blumenberg & Agrawalb, 2014).

Researchers use accessibility measures to assess equity issues, such as determining the number of jobs reachable by marginalized groups within a defined travel time threshold

and compare these measures across socioeconomic categories (Manaugh & El-Geneidy, 2012). Transit agencies appear hesitant to adopt any of these measures, and comprehensive transit access measures must consider the wide breadth of activities to live a complete and fulfilled life rather than only considering employment or another narrow definition of destination activity.

4.3.1. Previous Works by Agencies

Equity in transportation is most viewed through the lens of federal requirements for environmental justice (Brodie and Kennedy, 2017). Federal policy does not directly address transportation equity; however, existing legislation does provide guidance on factors to consider when developing performance measures. “Title VI of the Civil Rights Act of 1964,” which required that the providers of federal funds not discriminate based on race, color, and national origin, encourages equity in transportation systems, specifically public transit.

As a result of Title VI , all federal agencies need to merge environmental justice into their mission, including the transportation sector (FHWA, 2012). Title VI, as well as other executive orders and legislation, protect EJ populations, defined as low-income and minority (U.S. Department of Labor, 2014). Recent efforts to emphasize social equity in transportation are emerging as local, regional, and national governments have required agencies to identify and avoid impacts (disproportionately) to low-income and minority populations. The U.S. DOT has identified three strategies to address environmental justice (FHWA, 2012):

- Reduce adverse human health and environmental effects on EJ populations.
- Consider all potentially affected communities in the transportation decision-making process.
- Make sure that minority and low-income populations receive equitable benefits.

In 1993, the National Environmental Justice Advisory Council was established to provide recommendations to the Environmental Protection Agency on emerging issues; this action increased efforts to integrate EPA recommendations with the transportation sector (EPA, 2014).

More recently, the Federal Highway Administration has promoted environmental justice guidance for local transportation planning agencies as well as state Department of Transportation agencies through training, workshops, and case studies (FHWA, 2014). The FHWA (2015) released an Environmental Justice Reference Guide for FHWA staff in order to ensure compliance with EJ requirements through clarifying expectations, identifying best practices, and providing resources. Increasingly, agencies appear to recognize the importance of fully embracing the role of equity and justice in the transportation planning process, but much work will be required to see all agencies embrace change.

Some agencies have expanded the concept of EJ areas to encompass transportation-constrained populations, such as households without vehicles, disabled persons, and seniors (age 65+) (Wilmapco, 2013), referred to as transportation justice (TJ) areas.

Transportation justice can be referred to as the application of environmental justice principles to transportation through investigating mobility, access, and modal opportunity. Studies have shown that low-income, minority, and transportation-constrained communities are more at risk for being impacted by the environmental and systematic burdens of transportation development (Forkenbrock & Schweitzer, 1999). Therefore, TJ requires that transportation system planning, design, and construction processes be carefully evaluated to identify the nature, extent, and incidence of probable consequences, both favorable and adverse.

For equity analysis, the first step is to define which communities to include as transportation disadvantaged (named “Historically Marginalized Communities” or HMCs). Table 11 proposed measures to use as part of the analysis for indicating the transportation need of different neighborhoods; the list includes each factor’s quantitative definition and potential data source. This list may be expanded to include jurisdiction-specific TJ factors or other emerging environmental justice issues. The “Direction of Need” in Table 4.4 identifies whether a lower percentage indicates a higher need (Below Average), or a lower need (Above Average). For example, for the factor, school proximity, a lower percentage of area that is within the one-mile buffer indicates a higher need; therefore, the relative graduated scale should reflect this direction of need.

4.4. PERFORMANCE MEASURES DEVELOPMENT

After reviewing the previous works done by agencies, it is implied that: Agencies must incorporate equity considerations into federally funded transportation practices by engaging in participatory planning and accounting for disproportionate burdens and equitable receipt of benefits; still, the current procedures do not necessarily reflect incorporation of environmental justice analysis results and feedback into the decision-making process (Amekudzi et al,, 2012).To plan for equitable outcomes in transportation, performance measures and evaluation methods that support the integration of equity considerations in the planning process require development. Equity and justice do not easily occur within existing institutional structures.

This study considers the existing state-of-the-practice PMs, but by changing the focus to EJ populations, the researchers target the riders with the greatest need. This shift to focus on the EJ populations mirrors a few agencies’ approaches, but more closely aligns with the PMs recommended by researchers to evaluate transportation justice. The themes identified in Chapter 3 using focus groups and interviews form the foundation for the creation of the PMs using the needs and priorities of EJ populations. These innovative PMs evaluate the service effectiveness for EJ populations. These new PMs can help transit agencies or other transportation organizations provide better transportation services, and these metrics may also better capture the differences in needs between

captive and choice riders. Figure 4.1 shows the inputs and outputs of the PM development process. The following sections discuss the PMs related to each emerging theme and identify potential data sources.

Table 4.4: Transportation Justice Factors

Category	TJ Factor	Definition (Measure)	Possible source	Direction of need
Transportation and land use	Public transit Access	Percentage of area that is within one mile buffer of a fixed route transit or rail stop	BTS (2014)	Below average
	School proximity	Percentage of area within one mile buffer of a school	NCES (2014)	Below average
	Network connectivity	Percentage of area within one mile buffer of highway access point	BTS (2014)	Below average
	Mixed land uses	Percentage of area that is mixed land use	Local zoning board	Below average
	Flood hazard	Percentage of area that is designated by FEMA as 100 year floodplain	FEMA (2014)	Above average
	Crash rates	Percentage of crashes per year that are fatal	NHTSA (2014)	Above average
	Truck volume	Percentage of truck traffic per current annual average daily traffic rate	FHWA (2014c)	Above average
	Intermodal facilities	Percentage of transportation facilities with two or more types of connecting modes	BTS (2014)	Below average
Demographics	Race	Percentage of non-white population including two or more races	U.S. Census (2010)	Above average
	Limited english proficiency	Percentage of people who speak another language at home, and who speak English "less than very well"	U.S. Census (2010)	Above average
	Age	Percentage of population below the age of 18, and above the age of 65	U.S. Census (2010)	Above average
	Disability	Percentage of civilian non-institutionalized population with a disability	U.S. Census (2010)	Above average
Socio-economic	Economic development	Percentage difference in people employed between two different census years	U.S. Census (2010)	Below average
	Vehicles per household	Percentage of households with less than two vehicles per household	U.S. Census (2010)	Above average
	Household income	Percentage of households that are making less money than the average median household income of the area	U.S. Census (2010)	Above average
	Single parent household	Percentage of single parent household regardless of whether or not they have children under 18 as a compared to familial households	U.S. Census (2010)	Above average
	Cost of living	Percentage of people with a median Monthly Housing Costs for occupied housing units below the regional average	U.S. Census (2010)	Above average
	Travel time	Percentage of commuters spending more than the median travel time to work	U.S. Census (2010)	Above average

(Adopted from Beiler and Mohammed, 2016)

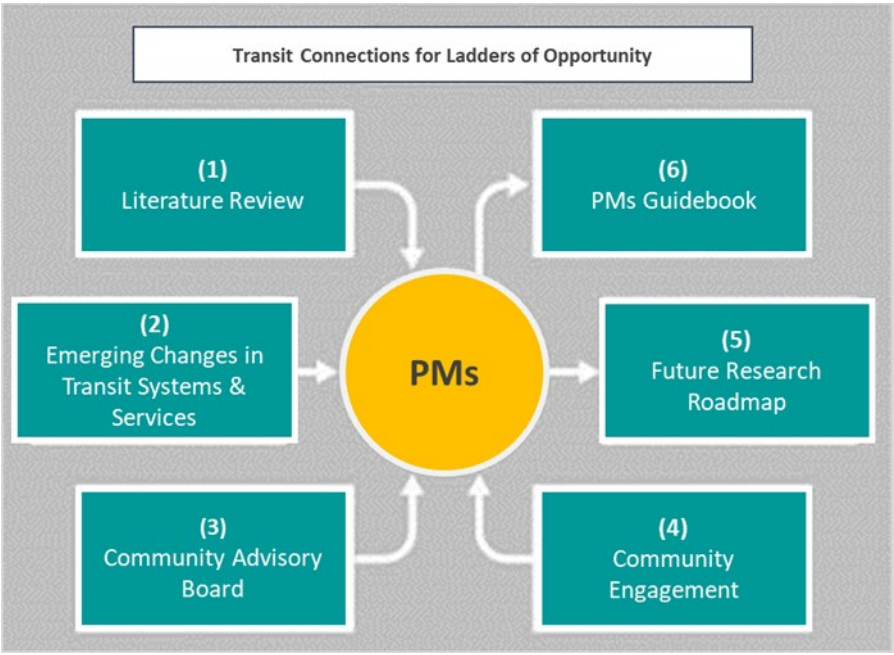


Figure 4.1: Input and Outputs in PMs Development Process

4.4.1.Access to Opportunities

This category of proposed performance measures focusses on transit system access and the access the system provides to opportunities. The focus groups and interviews both emphasize the need for these performance measures because the current systems do not appear to provide much access. These PMs emphasize travel time because as the travel time required to travel to different activities increases, the activities become less accessible due to finite time budgets. As a baseline assumption, the performance measures use walking speed (two to three miles per hour) to calculate total travel time; however, this can be adjusted for different first- or last-mile accessibility assumptions. The opportunities that require performance assessment appear in Table 4.5.

The synthesized performance measures for access to opportunities only consider the residents served by transit (i.e., “transit coverage” performance measures) intersected with the accessibility metrics. The spatial patterns of the accessibility performance measures can be assessed at the census tract or block group levels depending on available data aggregation. For the accessibility performance measures, the transit agencies may convert them into mobility measures by selecting normative travel times that align well with the mean travel times for the region for each activity or a national norm from the National Household Travel Survey. Mobility PMs capture headway decisions and emphasize total travel time, but access to opportunities begins with addressing transit system coverage and FLM access. Sections 5 and 6 provide a more complete description of the performance measures’ applications to evaluate system performance.

Table 4.5: Access to Opportunities PMs

Performance Measure	Performance Metric
Employment Accessibility	Number of Jobs with Annual Income < $15000
	Number of Jobs with Annual Income $15,000 - $40,000
	Number of Jobs with Annual Income > $40,000
Employment diversity	Jobs/Household
	5-Tier Employment Entropy
	8-Tier Employment Entropy
Education Accessibility	Number of 4-Year Public University Campuses
	Number of Community College Campuses
	Number of GED Completion Schools
	Number of Immigrant Language and Civics Schools
	Travel Time to Nearest Education Establishment
Food Accessibility	Number of Full-Service Grocery
	Number of Congregant Meal
	Number of Soup Kitchen
	Number of Food Bank
	Number of Markets with Fresh Produce
	Travel Time to Nearest Food Establishment
Social Accessibility	Number of Senior centers
	Number of Library Public recreation centers
	Number of Parks
	Number of Pools
	Number of Senior centers
	Number of Religious centers
	Number of Social Clubs
	Number of Veteran organizations
	Travel Time to Nearest Social Establishment
Shopping Accessibility	Number of shopping centers
	Square footage of retail
Transit Coverage	Households with access to a Transit Stop (%)
	Distance to the nearest transit stop
Disabled Access	Facilities with ADA compliance between transfer points (%)
	Disabled population with access to system per total disability facilities (e.g. wheelchair locks)

Access to Healthcare

These performance measures focus on transit system access to healthcare; they look like those from the previous section, but healthcare represents a major access category. The focus groups and interviews both emphasize the need for healthcare access. These PMs emphasize travel time because as the travel time required to travel to different activities increases. the activities become less accessible due to finite time budgets; the reasonable default travel time thresholds appear to be 30 minutes (routine care) or 60

minutes (specialized or less frequent care). As a baseline assumption, the performance measures use walking speed to calculate total travel time; however, this can be adjusted for different first- or last-mile accessibility assumptions. The performance measures for access to healthcare activities appear in Table 4.6.

PMs in this category, include different levels of healthcare requirements from basics. for instance pharmacies, to medium, such as dental and public health clinics and even advanced, same as hospitals to fully cover community needs.

Table 4.6: Access to Healthcare PMs

Performance Measure	Performance Metric
Pharmacies Accessibility	Number of Pharmacies
Public health clinics Accessibility	Number of Public health clinics
Dental public health clinics Accessibility	Number of Dental public health clinics
Hospitals Accessibility	Number of Hospitals
Health Institution Accessibility	Travel Time to the nearest Health Institution

4.4.2. Equity

The theme of equity does not have any specific performance measures. Instead, transit agencies should make service comparisons for different populations to ensure that the services the agencies provide remain equitable across these populations. The need for an equity assessment appears in both the interviews and focus groups because some individuals and communities feel forgotten by the transit agencies.

The frames of comparison should include demographic characteristics such as: gender ratio; single-mother led households; races and ethnicities (non-white)' EJ populations; different age groups; limited English proficiency; foreign born; low income; zero car; and disabled.

4.4.3. Economic Viability of Partnership or Strategy

This topic does not relate to any of the material from the community engagement because it focuses on the government support required to deliver different transportation services. In the context of this project, it focuses on the first-/last-mile strategies; however, it may be applied more broadly to transit or even automobile-focused infrastructure. The performance measures for this issue include total subsidy amount, subsidy/rider, subsidy/trip, and fare revenue.

In the context of this project the capital and operating costs of each first-/last-mile strategy represents the critical input. The costs may be borne by the users as a fare, which may affect affordability (see Section 4.4.9), or the costs may be covered by subsidies (usually governmental but possibly non-profit).

4.4.4. Partner Sustainability

This topic does not relate to any of the material from the community engagement because it focuses on the sustainability of the first-/last-mile solution or a public transportation service in general. These performance measures assess the support required to sustain the solution as well as the financial health of all partners. The performance measures for this issue include; amount of profit, source of subsidy, partner strength and other indicators of business financial health.

4.4.5. Limited Service Hours

Limited service hours represent a common theme in literature and the interviews identify this problem as well. This often happens because transit-captive riders may not have typical 8 a.m. to 5 p.m. work schedules, and a service that fails to accommodate these different schedules may represent a barrier to employment. For this topic, total hours of operation represent a possible performance measure that does not require supplemental data collection; however, another performance measure might be the percentage or total number of work trips occurring during nontraditional time periods (e.g., 10 p.m. – 12 a.m., 12 a.m. – 2 a.m., 2 a.m. – 4 a.m., and 4 a.m. – 6 a.m.).

4.4.6. Reliability

Reliability represents a common theme in both the focus groups and the interviews. The interviews and focus groups describe reliability in two ways. They discuss the travel time reliability or the ability to be on time to jobs and appointments, but they also highlight the service availability and the ways the service may be scheduled. Neither of these concerns directly link to first-/last-mile solutions; however, both may need to be captured in a holistic transit system assessment. The travel time reliability may be assessed using the following metrics:

- Delay risk – headway on a route multiplied by (probability of delay)
- State-of-the-practice reliability measures
  - Percentage of on-time arrivals
  - Mean route delays
  - 90th percentile delay
  - Delay variance
- Percentage of time service (e.g., docks empty for parking or vehicle available) available

4.4.7. Safety

The interview results agree with the transit agencies that use safety-related performance measures. The safety performance measures may include number of customer

complaints related to safety; number of crashes; number of crashes/one million miles of vehicle travel; number of minor injuries; number of minor injuries/one million miles of vehicle travel; number of severe injuries; number of severe injuries/one million miles of vehicle travel; number of fatalities; and number of fatalities/one million miles of vehicle travel.

4.4.8. Security

The interview results agree with the transit agencies that use security-related performance measures. Table 4.7 presents safety performance measures.

Table 4.7: Security PMs

Performance Measure	Performance Metric	Metric
Infrastructure	Lighting at transit stop	Brightness (Luminosity)
	Number of Security features (e.g., camera, cashless transactions)	Checklist
	Transit vehicles equipped to call 911	Fleet percentage
Reporting	Property crimes (US Census block group)	Crimes/10,000 residents
	Violent crimes (US Census block group)	
	Number of customer complaints related to security	Total complaints/ Total users @ location

4.4.9. Affordability

The focus groups and interviews both emphasize the need for transportation affordability. While affordability may be assessed in many ways, this report uses a strategy from literature; the H+T strategy combines housing and transportation expenses together to represent 45% of total income. Households that spend more than 45% of total income on transportation appear cost burdened (Center for Neighborhood Technology, 2017). This H+T strategy assumes that transportation expenses should equal 15% of total income or less.

Assessing this method requires identifying the cost to use transit using any reduced fare programs (if applicable). For each block group, the number of households falling below the transportation cost of 15% should be relatively straightforward by identifying the number of households in different income ranges and determining the target threshold for income to achieve affordability. Where possible, the housing costs for a block group should be included to fit the overall H+T strategy. The following bullets describe the key assumptions for the H+T analysis; however, the transportation expenses should equal 15% of total income or less may also be used. Adkins et al. (2020) contains an alternate approach to household affordability and well-being.

Additional affordability measures/issues to analyze are:

- Payment platform/strategy for unbanked; actually effective? How to measure effectiveness?
- Smartphone access required.
- Deposit and information challenges for sharing (scooter, bike, car).
- Use and qualitative data to assess.
- Public/private partnership with retail vendors.
- Voucher use.
- Mobility improvements/changes.
- Fare support/reduction programs.

4.4.10. Assistive Services

The interviews also identify the need for assistive services that enable all users to easily navigate the system. These services may receive many labels such as ambassadors or travel buddies, but they seek to enhance the ridership of transportation-disadvantaged populations. These may be evaluated as a simple checklist that describes the services provided by these transit agency volunteers or employees or using the number of volunteers or employees per total ridership from the target population or total target population within a quarter mile of a transit stop. The transit agency may decide to use these different approaches based on their goals associated with using the performance measure.

4.4.11. Built Environment

The interviews recognize the importance of the built environment for supporting transit usage; however, in most cases, the built environment remains beyond the control of the transit agencies. Regardless, neighborhoods may be evaluated to consider; sidewalks (present or not); bike lanes (present or not); walkability score for neighborhood; bikeability score for neighborhood; and the checklist of transit stop enhancements (percentage of stops with the enhancements: equity evaluation, shelter, bench, and time bus arrival kiosk).

The transit stop enhancement checklist requires further development to identify all the possible enhancements; the enhancements may evolve over time, but transit agencies should be able to identify the current options. All these performance measures require infrastructure inventories; the bikeability and walkability scores require more effort to complete than the other inventories.

5 PERFORMANCE MEASUREMENT APPLICATION METHODS

5.1 ACCESS TO OPPORTUNITIES

The previous chapter defines 11 performance measures: equity, access to opportunities, economic viability, sustainability, limited-service hours, reliability, safety, security, affordability, assistive service and built environment. These 11 PMs can be classified into two major categories: Accessibility and transit service improvement. For EJ cases who are the target population for this study, accessibility seems more important than transit service improvement because they need to reach transit firstly and then transit service quality will be an issue. Transit improvement will help users to choose between different options; however, the disadvantaged population are mostly transit-captive users, so they have limited options. Therefore, among all proposed PMs, the study investigates accessibility using different FLM alternatives to show its application, compare and contrast FLM alternatives, and examine their implications for a transit agency.

5.1.1 FLM Analysis Method

This section proposes an analysis method for evaluating FLM strategies such as walking, biking, and ride hailing which connect transit users to transit stops. Facilities such as transit stops, pedestrian walkways, and bike lanes are required to encourage modal alternatives in place of the automobile (especially for the non-driving population). Therefore, ensuring all communities have access to mode choice is essential and can be supported with well-connected street networks, mixed land uses, and reasonable travel times. In addition to the infrastructure in place, the cost of transportation, the accessibility, and language barriers can influence mode choice and FLM choice.

Therefore, identifying community needs is essential to provide effective and equitable transportation services. This relates to the transportation and opportunities (such as public transit access, job proximity, service accessibility and network connectivity), which provide insight into the availability of FLM options based on infrastructure design and transportation planning.

5.1.1.1 Threshold Development

The focus groups, interviews and surveys emphasize the importance of transit travel time and FLM strategy when characterizing transit accessibility. Transit riders include choice users and captive users. While choice users select to use transit rather than automobile or other automobile service, captive users usually only have the choices of walking or asking others for an automobile ride other than transit.

This study focuses on the captive riders within the EJ population to emphasize the service of the most transportation disadvantaged. The transportation disadvantaged usually come from low-income households or are unable to drive (age-related or physical disability-related). These include low-income households; low-income single parents; people who are too young or too old to drive; people with disabilities; limited English

proficiency; and recent immigrants from developing countries. Full participation in society for the transportation disadvantaged requires a transportation system that meets their transportation needs.

Transit agencies, planners, and research rarely linked data such as origin destination patterns, quality of transit access, service characteristics, and household situations in a useful way to predict transit use and transit need. Beimborn et al. found that high levels of transit use occurs when transit stops/stations are in reasonable proximity to both the origins and destinations (Beimborn, Greenwald & Jin, 2003). Furthermore, Crowley et al. (2009) quantitatively illustrated the strong association between convenient walk access, lifestyle, and transit use, not only during peak hours but also throughout the day. Transit users moving under their own power have different use characteristics and functional needs from one another, based both on the physical requirements of chosen access mode and personal characteristics including age, ability and personal attitude towards risk and comfort. Not all transit users can walk 20 minutes or bike for 30 minutes. A healthy 17-year-old skateboarder has very different mobility characteristics and needs from a 91-year-old utilizing a wheeled push-walker. This research aims to understand these differences, improve on the planning and design of existing facility options, consider how to better support a broader range of personal mobility, and maximize transit integration all within a complete street's context.

The proliferation of personal mobility devices by all age groups, from ride hailing to bicycles to walking, presents a tremendous opportunity to extend the reach of public transit investments. For instance, for the walk option, the time required to walk to a station determines transit access. According to Fitzpatrick et al. (1982), average pedestrian walking speed is three mph; however, the exact number is age-related.

This study considers a bicycle of 10 mph because it is adopted by many transit agencies. The same speed is acceptable for scooter as well, so all the access analysis for the bicycle may work for scooter, too. The study investigates access to opportunities using different FLM strategies and their associated access times. Specifically, this study examines the population with access to transit using access and egress travel times for the FLM options of five and 10 minutes.

Figure 12 shows the distance and assumed speed for each of the FLM options. To find distances, a simple formula is used as:

$X = Vt$

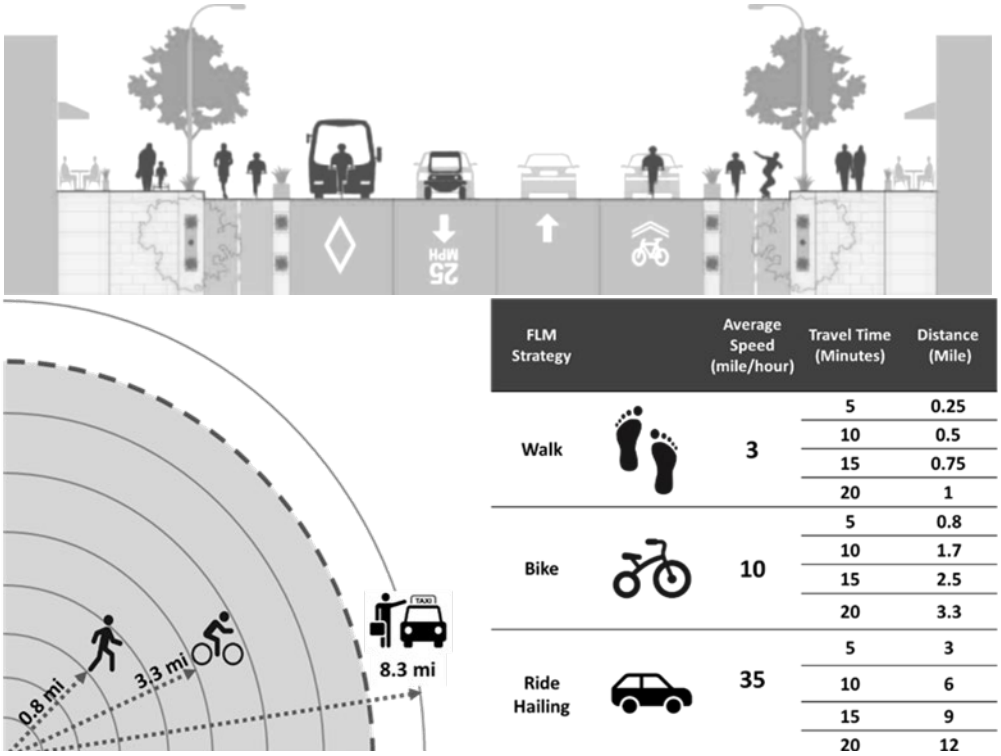
X= distance (mile)

V= Speed (mile/hour)

T= travel time (hour)

5.1.1.2 Methodology

Using the access travel time, the study generates a multiple ring buffer for distances associated with each FLM alternative and access time combination. The buffers' radiuses use the average speeds for FLM strategies shown in Figure 5.1.



FLM Strategy	Average Speed (mile/hour)	Travel Time (Minutes)	Distance (Mile)
Walk	3	5	0.25
		10	0.5
		15	0.75
		20	1
Bike	10	5	0.8
		10	1.7
		15	2.5
		20	3.3
Ride Hailing	35	5	3
		10	6
		15	9
		20	12

Figure 5.1: FLM Accessibility Thresholds

The study also locates the opportunities (health centers, education establishments, etc.) and bus stops on a BGs map in Arc GIS and overlays each buffer with opportunities locations to determine the opportunities located inside each buffer. For instance, for a hypothetical user, with the average walking speed of three mph, a 15-minute walk to a transit stop equals a half-mile distance. Thus, a circular buffer with 0.5-mile radius is created and those destinations located within the buffer have access to transit stops for this access case.

For calculating the population who have access to opportunities with transit for different FLM options and access time (population coverage) cases:

Firstly, the analysis identifies the portion of BGs within with the buffer area by utilizing this formula: (Joint Area/ BG Area) *100

The study estimates the population served by using the ratio for the area coverage multiplied by each corresponding BG population. The sum of the population coverage of all BGs shows the total coverage for different population groups over the entire county. The analysis repeats this process for all the cases enumerated by Figure 5.2.

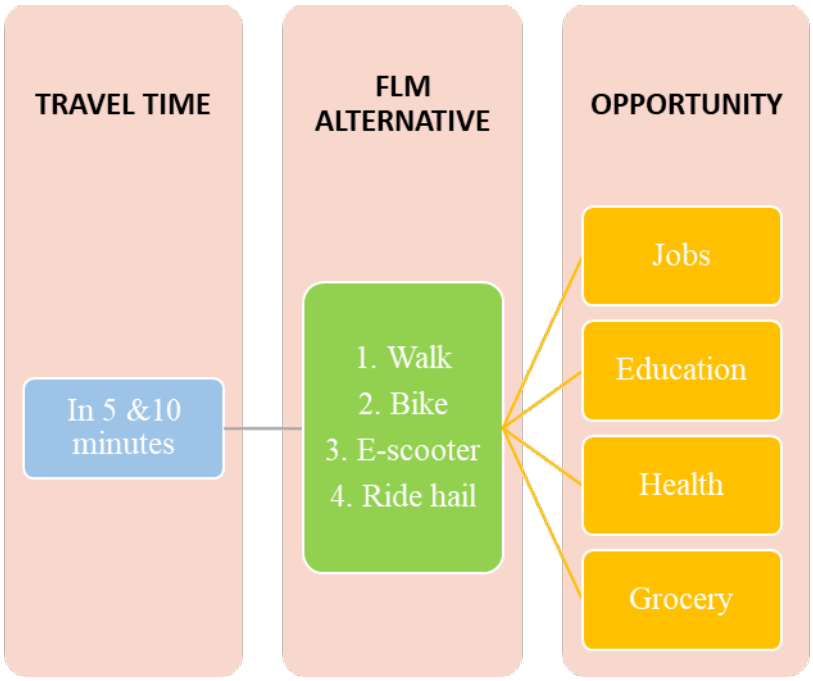


Figure 5.2: Selected PMs

5.2 EQUITY

Improving transit-based accessibility to a wider range of opportunities by providing FLM options appears vital to advance a more equitable society. To that end, the study identifies accessibility to jobs, health, education, and food as essential opportunities for a quality life. When evaluating access for all, transit agencies must consider the different use characteristics and functional needs among transit users, based both on the physical requirements of the FLM alternative and personal factors such as age, ability and personal attitude towards risk and comfort.

This research enables transportation authorities to evaluate the transit coverage by different FLM alternatives and verify that they align well with population needs; they can use these performance measures when making investments to support a broader range of personal mobility and maximize transit integration within a complete street context. To value the disadvantaged population's special needs and preferences in terms of costs and physical restrictions and cover a full demographic range of users, the study creates three user scenarios for equity analysis that align with the walk, bike and ride hailing options. For instance, the disabled population may have ambulatory difficulties and struggle using the active FLM options such as walking or biking. Table 15 presents the characteristics of three scenarios.

5.3 ECONOMIC VIABILITY

In the context of this project, the capital and operating costs of each first-/last-mile strategy represents the critical input. The costs may be borne by the users as a fare, which may

affect affordability (see Section 5.9), or the costs may be covered by subsidies (usually governmental but possibly non-profit). Transit agencies provide the required data for this category in any future analysis, such as cost associated with an infrastructure enhancement or providing a FLM alternative.

5.4 SUSTAINABILITY

These performance measures may be applied for specific case studies or alternative comparisons, but they do not have a role in the assessment of the first-/last-mile strategies in the assessment in this project because this study does not investigate and consider specific financing strategies, actual business partners, or business agreements.

5.5 LIMITED SERVICE HOURS

Not all employees work during traditional working hours. Specifically, for EJ cases, they may have limited options for choosing a job, so they may choose a night-shift job. Therefore, the origin destination patterns for EJ populations may require extended operating patterns, but this analysis requires collecting latent or needed trip data rather than observed trip data. The latent demand pattern may be collected using MyAmble (Fields et al., 2020) or another similar survey instrument. This performance topic does not easily apply to first/last-mile solutions unless their operating hours differ from the transit service.

5.6 RELIABILITY

Evaluating the service features does not necessarily work well at an aggregate level because different individuals may prefer different features. However, this report identifies some of the features that may be potential features to consider. In the future, a more detailed data collection effort may be able to identify additional service features, which require tracking of unserved trip requests, prescheduling of service requirements, stop arrival variance, equipment failure rates, on-time rates for each stop and line, and service reservations available.

5.7 SAFETY

This performance measure may play a role in first-/last-mile solution evaluation when the crashes and crash outcomes (e.g., injury or fatality) for FLM alternatives. This category may identify crash and/or conflict hotspots for FLM alternatives and link to the built environment (infrastructure) supporting the FLM alternatives.

While most agencies consider “number of fatalities” as the most important measure in transit safety, many agencies have adopted a total societal or social-cost approach to measurement using the *Highway Safety Manual*. This implies that the agencies value the impact on society of fatalities and injuries in a broad context. A successful safety program requires a data collection and analysis system that provides continual information on the safety performance of the transportation system. This information is used to monitor progress toward performance targets, identify topics or areas where further action is

necessary, educate officials and the public on the importance of the topic, and evaluate the effectiveness of implemented strategies (FHWA, 2004). Since many FLM alternatives are also vulnerable modes, the conflicts with motor vehicles represent an important metric to track because the first crash at a location may become a fatality.

Transit agencies should have access to the data needed to calculate many safety PMs using state crash databases, but conflicts may require a separate systematic and comprehensive data collection and analysis program. In each case where a database management capability exists, it should be integrated into the geographic information system (GIS) to portray the locations and characteristics of the safety data with respect to the public transportation system, population, and FLM infrastructure.

5.8 SECURITY

These performance measures require supplemental data collection and inventories of the infrastructure in the transit network. The passenger complaint collection requires a mechanism for collecting and organizing the complaints, and the crime statistics must be collected at a geographic unit of analysis that aligns well with the population measures used in Sections 5.1 and 5.2. The checklist of desirable security features represents an evolving checklist where the security features may change over time. Regardless, the security feature checklist requires additional insights from a security consultant.

Transit and law enforcement agencies will provide data required for this category of PMs. This PM category will have minimal impact on FLM alternative because most FLM alternatives leave travelers vulnerable to security concerns.

5.9 AFFORDABILITY

While the exact method of assessing affordability may vary among agencies, the comparison of FLM alternative solutions should use a percentage of the households able to afford transit originally that can still afford transit plus the FLM solution. Transportation affordability refers to the financial burden households bear in purchasing transportation, particularly those required to access basic services and activities such as healthcare, shopping, school, work, and social activities. This generally means that households can spend less than 20% of their budgets on transport, or less than 45% on transport and housing combined. Many households, particularly those with lower incomes, spend more on transport than is considered affordable. Several factors can affect transport affordability, including the quality and price of transport options, land use accessibility, and housing affordability. Affordability is an important issue to transport system users, but conventional transport planning usually considers a limited set of costs and so is ineffective at evaluating overall affordability. More comprehensive analysis is needed for comprehensive affordability analysis. Previous studies indicate that affordability increases with more accessible development and more multimodal transport planning and declines with sprawl and automobile dependency. Strategies that improve affordable modes tend to provide co-benefits (Litman, 2020). Since the FLM alternatives have different travel

times, this performance measure directly connects to transit accessibility discussed in Section 5.2.1.

5.10 ASSISTIVE SERVICES

A checklist that describes the assistive services provided by the transit agency volunteers or employees or using the number of volunteers or employees per total ridership from the target population or total target population within a quarter mile of a transit stop will be helpful. The transit agency may decide to use these different approaches based on their goals associated with using the performance measure. This approach of creating a simple checklist of services provided requires additional data collection from social workers and transit agencies to determine the full range of services that these assistive programs may provide. The checklist should be developed to capture the range of potential services that a transit agency may offer to assist all riders. This performance measure topic does not connect to the evaluation of FLM alternatives because the FLM alternatives appear unlikely to be impacted differently by these assistive services outside of bicycle racks on transit vehicles or at stops.

5.11 BUILT ENVIRONMENT

Walk: FLM strategies need improvement in infrastructure. The first requirement for walking is a continuous, direct path with adequate sidewalks and crossings, with the emphasis on orthogonal street grids with short blocks, carefully planned mid-block pass-throughs, or paseos where blocks are too long, and reducing crossing of barriers, such as highways, railroad tracks, large inaccessible parcels and canals or rivers. The secondary considerations are traffic safety and security. The emphasis is also on sidewalk adequacy, crosswalks, and traffic signal operations that prioritize quick and safe access for pedestrians to cross streets.

Bike: Biking also requires the greatest emphasis on creating continuous, direct paths. Barriers such as highways, railroad tracks, large inaccessible parcels, and canals or rivers, should be considered for bridging. The secondary considerations are traffic safety and security. Planning and implementation of continuous, direct bicycle facilities as appropriate to traffic conditions, vehicle mix, vehicle speeds, and pedestrian volumes. Riders (both experienced and less experienced) prefer minor streets and bike lanes – underscoring the need to be protected from higher speed traffic. Riders also need protection from parked cars' maneuvers and opening doors. Bike lanes should be buffered from traffic, but are preferably located away from parking lanes or to the right of the parking lane with the buffer alongside the parking lane. Storage for personal bicycles should be secure from theft and vandalism, and well protected from weather.

Ridesharing: Infrastructure and programmatic needs for ridesharing include policy support, seamless information integration, and provision of safe pickup and drop-off spaces at the primary transit station and throughout the station areas.

6 CASE STUDY

6.1 GTFS DATA COLLECTION AND PRE-PROCESSING

The study used the Dallas Area Rapid Transit (DART) General Transit Feed Specification (GTFS) data for May 2020 for developing the transit. Dallas County covers a total area of approximately 908.5 square miles with a population density of 2,993.57 people per square mile. Dallas County, home to 1.3 million people, is predominantly urban, with 99.42% of its population living in urban areas. DART provides public transit services across a 700-square-mile area which includes Addison, Carrollton, Cockrell Hill, Dallas, Farmers Branch, Garland, Glenn Heights, Highland Park, Irving, Richardson, Rowlett, Plano, and University Park. The transit options include DART Light Rail, Trinity Railway Express commuter rail, bus routes, GoLink on-demand services, and paratransit which serves around 220,000 passengers on average across the Dallas area. Out of which around 83,000 people per day use DART busses. DART has a bus fleet of 692 with 6,878 bus stops and 14 bus transit centers.

The DART GTFS provides detailed transit network data and descriptions including the geolocation of transit stops, travel time between stops, travel time by time of the day, and route structure. The study pre-processed the GTFS data to create some transit system characteristics because the GTFS data provides trip information consisting of trip number and stops associated with trips separately from the relationship between trips and route information. The study needed to identify the stop-to-stop distance of every route based on this information. Since the peak hour typically provides the shortest headways and most complete route structure in the DART network, the study only used the data for peak hours to determine access and travel times. The study calculated the shortest time from each transit stop to all the accessible transit stops in the DART network.

This study developed a modified version of Dijkstra's algorithm to incorporate wait time while finding a new shortest path. A traditional application of Dijkstra's algorithm fails to address the average waiting time for passengers at a transit stop where the waiting time may occur at the beginning of a trip before they board a transit vehicle or when they must transfer to another bus or train to complete their trip. The study assumed a waiting time equal to half the headway of the route for the origin bus stop and all transfer locations. This approach did not capture the reduction in average waiting time that might occur from improved information provided to DART customers and DART efforts to coordinate bus arrivals at transfer nodes. While the transit travel times might decrease after including these factors, the approach currently used more accurately reflects limited customer information (which appeared more likely for transportation-disadvantaged populations) and the risk posed by bus delays that fail to coordinate bus arrivals. The modified algorithm provides a transit travel time matrix that connects all the transit stops together.

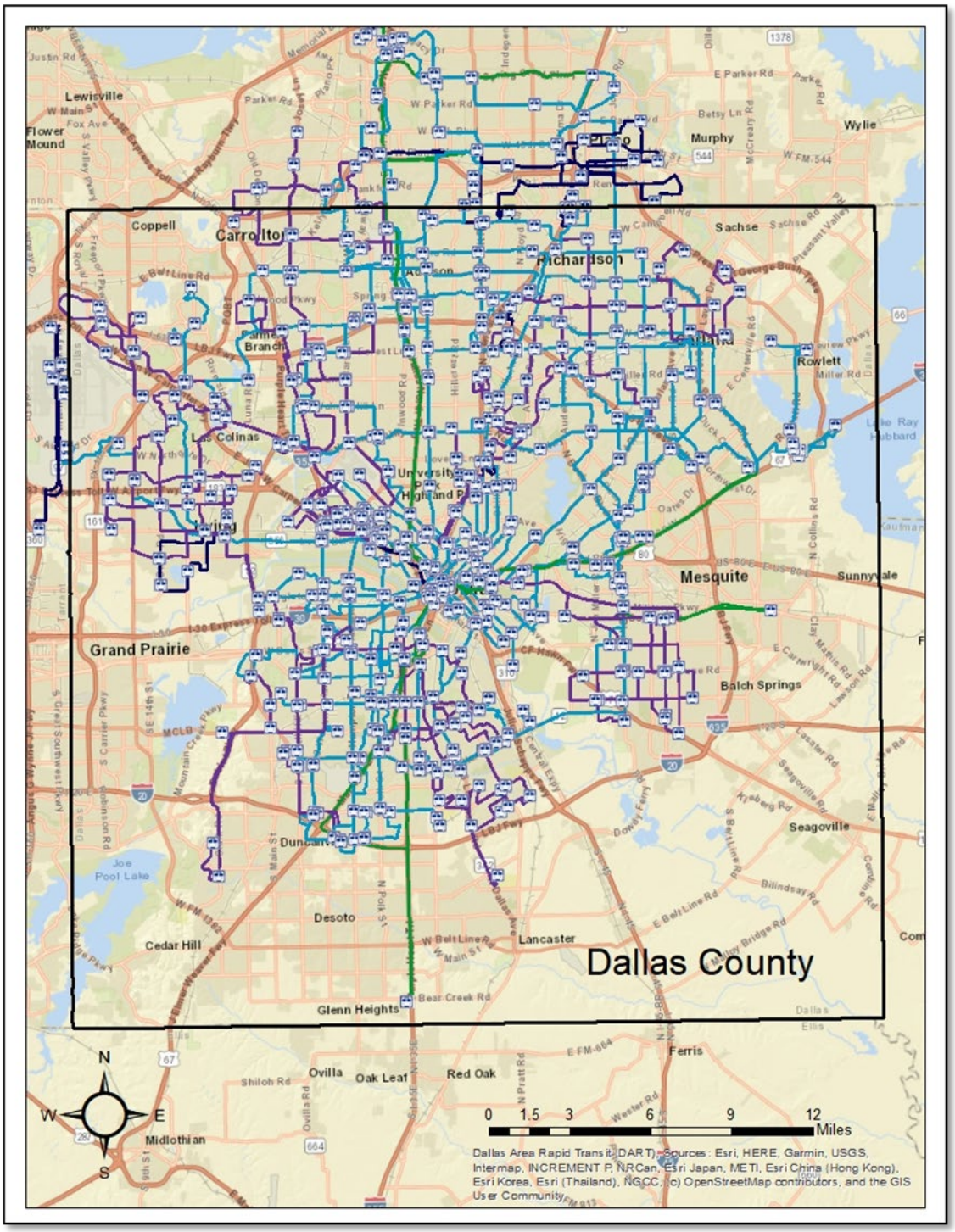


Figure 6.1: Dallas County Area and DART Service Map

6.2 BUFFER ANALYSIS

This section presents performance measures related to access to opportunities for Dallas County to illustrate the application of the proposed performance measures. The report proposes a methodology where an analyst uses ArcGIS to develop buffers around all

opportunities to calculate the number of transit stops, which can supply access to a particular opportunity. The analyst must also generate buffers around each transit stop for access times of five and 10 minutes using Euclidean travel times for each FLM alternative. The transit stop buffer identifies the number of households with access to the transit stop. Figure 6.2 shows the buffer generated for 10 minutes FLM travel time using a bike, which results in a buffer radius of 0.66 mile. Table 6.1 shows the buffer radius in miles for each FLM alternative and opportunity for five- and 10-minute FLM travel times.

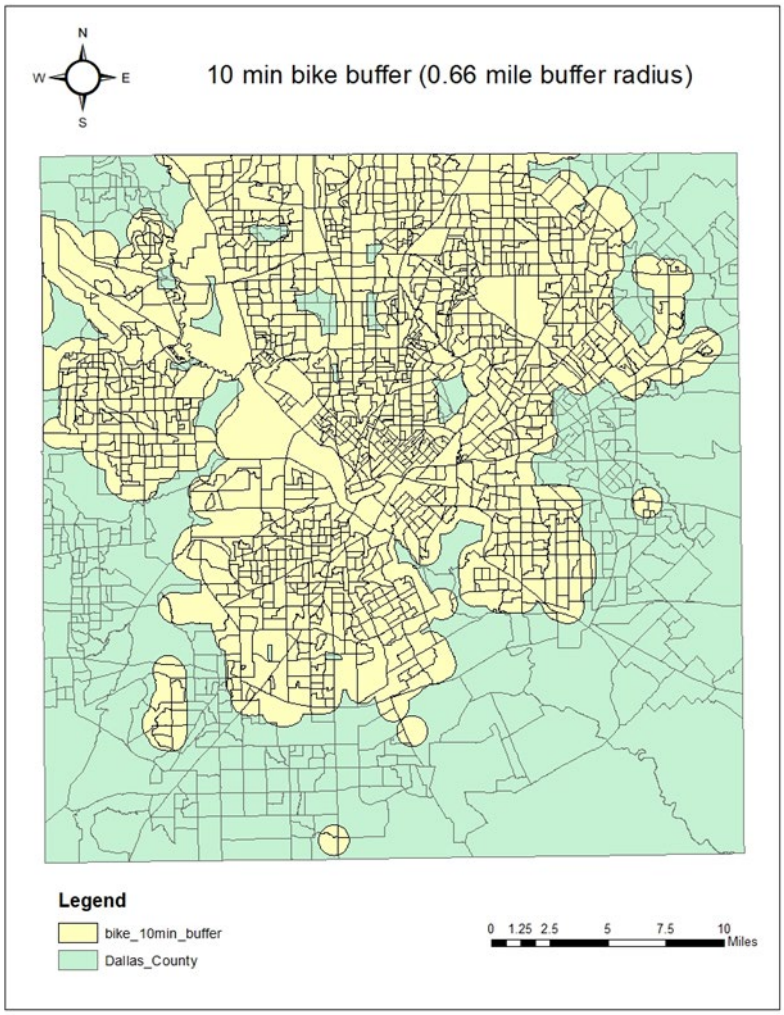


Figure 6.2: Buffer Area for 10-minute FLM Bike Travel Time

Table 6.1: Buffer Radii for Five-minute and 10-minute FLM Travel Time

FLM Alternative	5 minutes	10 minutes
Walking	0.25 mile	0.5 mile
Biking	0.33 mile	0.66 mile
E-scooter	0.41 mile	0.83 mile
Ride hailing	3 miles	6 miles

6.3 ACCESS TO OPPORTUNITIES

This study investigates public transportation access to specific opportunities (e.g., education, groceries, hospital and employment) using different FLM alternatives. This study also uses an equity lens to evaluate access to opportunities. This study considers four FLM alternatives; walk, bike, e-scooter and ride hailing to generate five- and 10-minute buffers around the transit stops to evaluate access to opportunities.

6.3.1 Accessibility with Travel Time

This performance measure focuses on the access the system provides to opportunities. It emphasizes travel time because as the travel time required to travel to different activities increases, the activities become less accessible due to finite time budgets. The study determines the travel time between trip ends including a production trip end (e.g., home) to an origin transit stop, between transit stops, and the destination transit stop to the attraction trip end (e.g., hospital, community college, or grocery store). By integrating this travel time with the population covered for the corresponding FLM and transit service, this study determines the accessibility of the serviced population. Each FLM alternative has different travel speeds from the trip end to a transit stop. For the sake of public transportation users, this study uses three, four, and 36 mph as the average speed for walk, bicycle, and ride sharing/ride hailing access, respectively.

6.3.2 Population Coverage - Accessibility

Using the public transportation accessibility generated for each FLM alternative, the accessibility performance metric considers the number of residents served by transit and the corresponding FLM options. The study uses Euclidean buffers to determine the population with access to a transit stop using a FLM alternative; the buffer size changes depending on the speed of the FLM alternative. Therefore, a buffer that provides five-minute access time for ride hailing serves a much larger area and more population than a buffer for a five-minute walk.

The portion of the BG within a buffer around a stop indicates the proportion of the total population with access to the transit stop, with the corresponding FLM alternative as follows:

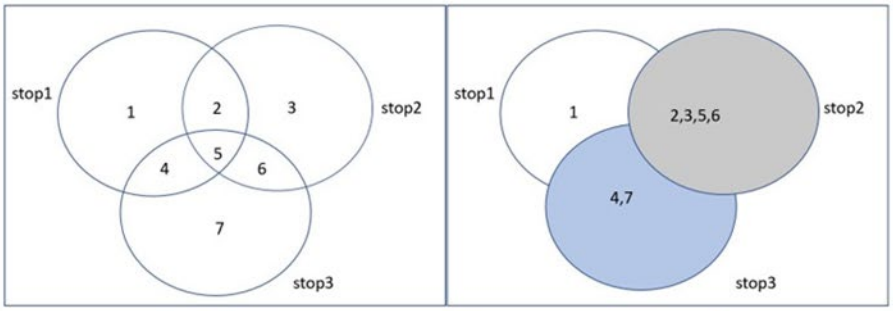
Transit coverage ratio = (Coverage Area/ BG Area) (eq. 1)

The analysis multiplies the transit coverage ratio by the BG population to estimate the amount of total population within each BG with access to opportunities using the various FLM options. The study uses the BG socioeconomic proportions to estimate the total population coverage for different population groups within each BG. The sum of the population coverage across all BGs shows the total coverage for different population groups over the entire county.

The average speed assumptions and access times may inaccurately portray the actual access observed by residents when poor pedestrian facilities and barriers cause FLM alternatives to perform more poorly than expected. Personal security and safety concerns may also reduce the accessibility experienced by residents or opportunities. Crime rates

may be used to help agencies introduce accessibility modifiers to the access measures; however, these concerns represent factors to consider when evaluating a public transportation system rather than developing a generalized methodology for evaluating FLM alternatives. This study does not assume such barriers and entirely depends on the accessibility provided by FLM alternatives. Multiple transit stop buffers frequently overlap the same areas because the public transportation system often has stops close to one another. This creates a significant challenge to accurately determine the population served by each transit stop.

This study uses a new approach to handle these overlaps served by an FLM alternative. For a particular block group, the study identifies the lowest travel time buffer covering the block group; the proportion of the block group covered by this buffer can be assigned to this transit stop and its corresponding travel time. Then, the study considers the next lowest travel time buffer and the proportion of the block group covered by this buffer after excluding the area assigned to the previous buffer. Figure 6.3 illustrates an example. This sample census tract is covered by three stops and their access buffers overlap each other. The chart in the figure shows the areas in the block group served by each stop and the travel times from these stops to the closest hospital. Stop 2 has the lowest time to the hospital. So, the households in area 3 as well as those in overlapping areas 2,5, and 6 will use stop 2 and its shorter travel time to take transit to the hospital. The next fastest travel time is from stop 3. Therefore, after excluding the areas served by stop 2, areas 4 and 7 will use stop 3 to travel to the hospital. The households in the remaining area, area 1, will choose stop 1 to visit the nearest hospital. This process proportionally allocates the block group households to the appropriate shortest path.



Stop Names	Duration to the closest hospital	Area covered by each buffer	Area distributed based on shortest time
Stop 1	10 min	1,2,4,5	1
Stop 2	5 min	2,3,5,6	2,3,5,6
Stop 3	8 min	4,5,6,7	4,7

Figure 6.3: Overlapping Buffer Region Methodology Example

The spatial patterns of both of accessibility performance measures (e.g., travel time and population served) can be assessed at any geographic level such as census tract or block group levels, depending on the available data aggregation.

6.4 Five-Minute Analysis:

Figures 6.4, 6.5 and 6.6 show the total travel time distribution by the percentage of the households within the given a five-minute FLM alternative buffer to access hospital, education, and groceries, respectively. For a five-minute buffer, walking generates the smallest buffer with a 0.25-mile radius and ride hailing creates the largest buffer with a three-mile radius. All of the figures show similar properties among different FLM alternatives. Ride hailing always appears as the best option for all three cases. At least 60% of households can access any opportunity within 20 minutes by using ride-hailing as a FLM alternative, but the situation reverses for walking as a FLM alternative. The analysis shows less than 5% of households will be able to reach an opportunity when they only allocate five minutes for walking to a transit stop. The five-minute bike and e-scooter cases show better access to opportunities than a five-minute walk to the transit stop. Among these alternatives, e-scooter represents the best alternative. Almost 50% of households can reach a grocery store within 30 minutes using an e-scooter as a FLM alternative option. The percentage decreases for access to hospitals or education facilities. Around 25% of households can travel to hospitals and education facilities using e-scooter, which still exceeds the biking and walking modes. Walking to transit stops seems infeasible for more than 30% of households as they require more than one hour to reach education and hospital facilities using transit. Therefore, faster FLM alternatives to transit stops appear essential to encourage people to use transit as their primary mode of transportation.

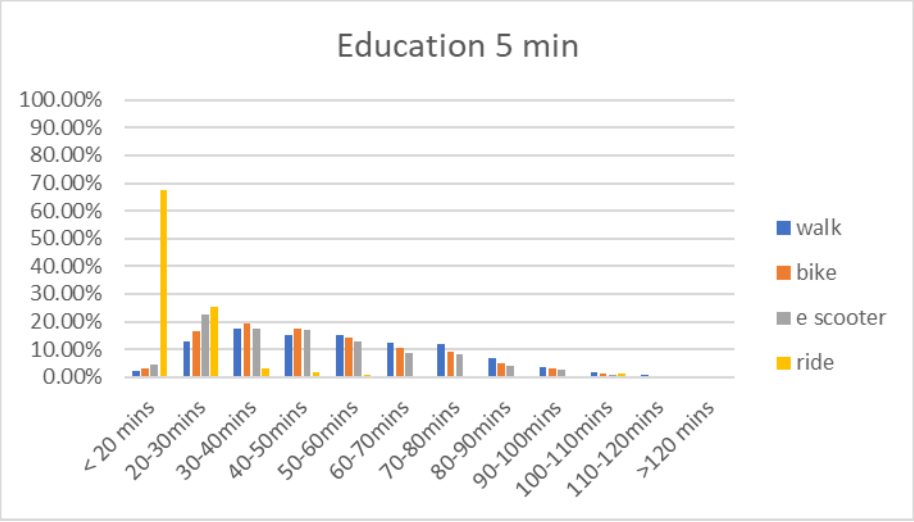


Figure 6.4 Household Distribution to Access Education

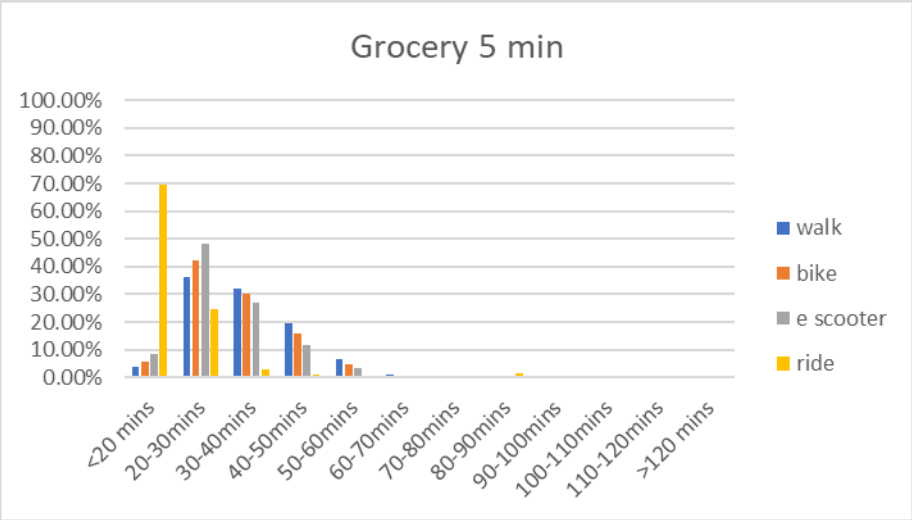


Figure 6.5: Household Distribution to Access Grocery

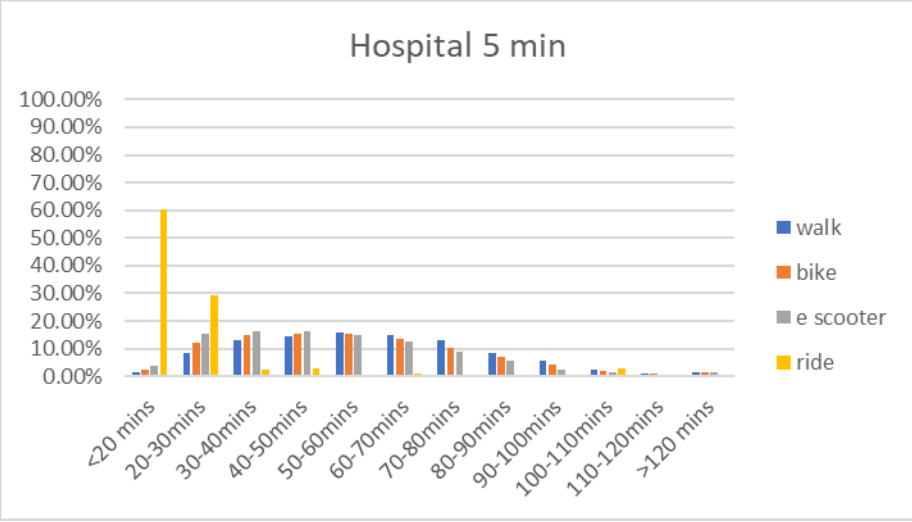


Figure 6.6: Travel Time Household Distribution for Households to be able to Access Hospital

6.5 10-MINUTE ANALYSIS:

Figures 6.7, 6.8 and 6.9 show the distribution of percentage of households within the given 10-minute FLM alternative over the total travel time to hospital, education, and groceries, respectively. For a 10-minute buffer; the smallest buffer, 0.50-mile radius is generated for walking and the largest buffer, six-mile radius, for ride hailing as FLM alternative. The figures indicate that ride hailing as a FLM alternative provides timely access (less than 30 minutes) to the opportunities for more than 90% of the households with access. However, ride hailing access must be subjected to an affordability constraint, too. The total travel times for walking, biking, and e-scooter as FLM alternatives have varied distributions of households from 20 minutes to 120 minutes. However, most residents access opportunities in ***90*** minutes or less.

Like the five-minute case, ride-hailing is the fastest way to travel to any opportunity. More than 90% of households can travel to education, hospital, or grocery stores within 30 minutes by transit, using ride-hailing as a FLM alternative with either 10 minutes of ingress or egress. Most households can travel to any opportunity by traveling only 10 minutes on transit if they use 10-minute ride-hailing as a FLM alternative. Like the five-minute case, an e-scooter seems to be the best alternative. More than 80% of households can travel to grocery stores using transit and e-scooter as a FLM alternative within 40 minutes. Its slightly higher speed makes it better than basic bike-rider access because more than 70% of households with basic riders can travel to grocery stores within 40 minutes. The situation improves for the 10-minute walk alternative, but almost 20% of households still require more than an hour to reach education or hospital facilities. Both the five-minute

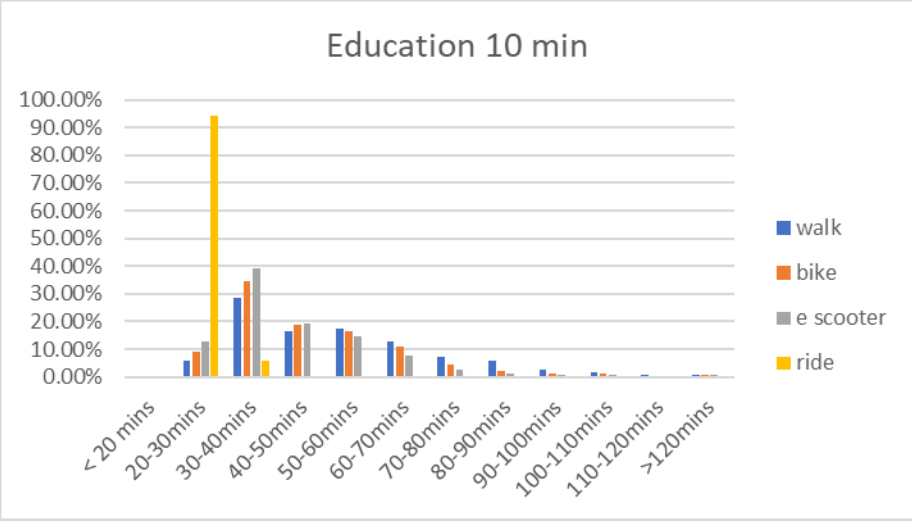


Figure 6.7: Household Distribution to Access Education

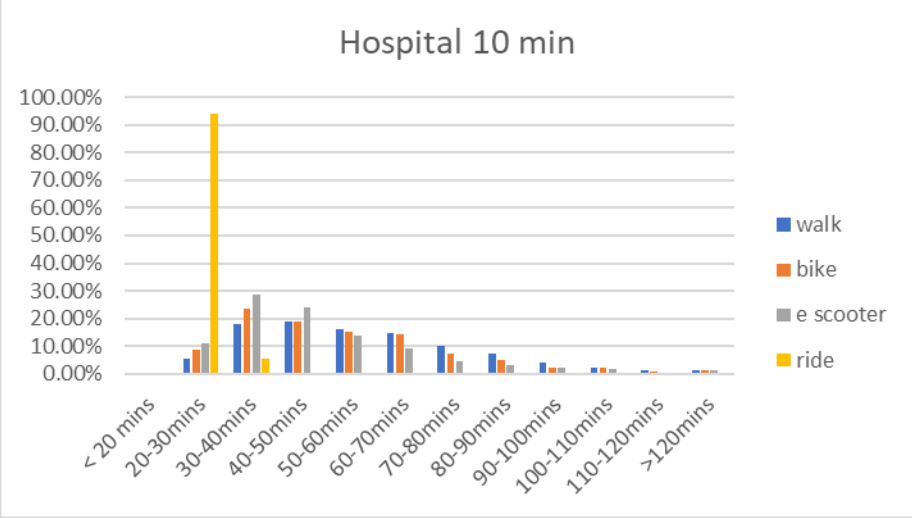


Figure 6.8: Household Distribution to Access Hospital

and 10-minute FLM alternatives show that people need faster alternatives to access transit stops to improve their access to opportunities.

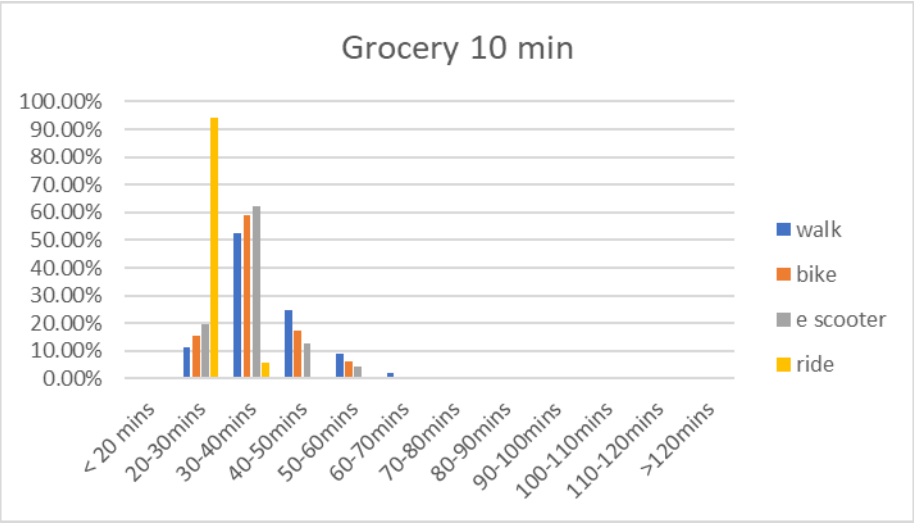


Figure 6.9: Household Distribution to Access Grocery

6.6 EQUITY ANALYSIS

This study assesses equity by comparing performance across different demographics such as race, ethnicity, disability, and car ownership using proportion tests. The equity analysis considers access to transit, access to opportunities (Section 6.7), and access plus affordability (Section 6.8) for each FLM alternative. This explains the impact of different FLM strategies on a population's access to opportunities. Tables 6.2 and Table 6.3 show the statistical significance (proportion test at 95% confidence) of differences in access when comparing vulnerable populations with a reference group for different FLM strategies using the five-minute and 10-minute buffers. Black households fare poorly with respect to white households for three FLM alternatives using a five-minute (bike, e-scooter and ride hailing) or 10-minute buffer (walking, bike and e-scooter). Households with a disability experience significantly lower access than households without a disability for both buffers using any of the four FLM alternatives. Hispanic households experience lower access than white households for the five-minute ride hailing buffer and the 10-minute bike to access transit. Whereas, for 10 minutes the proportions are lower for bike and e-scooter alternatives. Asian households do not show a significant difference in access from white households and households without a car do not show a significant difference in access from households with a car for both buffers using any of the four FLM alternatives.

For each FLM alternative, the analysis only considers the proportion of each population group with access to transit stops; however, the analysis compares the mean total travel times to assess any differences present for each FLM alternative.

Table 6.2: Statistical Significance of Different Demographic Groups within Five-minute FLM Buffer.

Proportion Test	5 min walk to bus stops	5 min bike ride to bus	5 min e-scooter ride	5 min ride hailing to bus
Significantly Lower proportion of black households with transit access than white households.	NOT SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT
Significantly Lower proportion of hispanic households with transit access than white households.	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT	SIGNIFICANT
Significantly Lower proportion Asian households with transit access than white households.	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT
Significantly Lower proportion of households with a disability have transit access than households without disability	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT
Significantly Lower proportion of households without a car have transit access than households with cars	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT

Table 6.3: Statistical Significance of Different Demographic Groups within 10-minute FLM Buffer.

Proportion Test	10 min walk to bus stops	10 min bike ride to bus	10 min e-scooter ride	10 min ride hailing to bus
Significantly Lower proportion of black households with transit access than white households.	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	NOT SIGNIFICANT
Significantly Lower proportion of hispanic households with transit access than white households.	NOT SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	NOT SIGNIFICANT
Significantly Lower proportion Asian households with transit access than white households.	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT
Significantly Lower proportion of households with a disability have transit access than households without disability	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT
Significantly Lower proportion of households without a car have transit access than households with cars	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT

6.7 ACCESS TO OPPORTUNITIES

6.7.1 WALKING

Tables 6.4 and 6.5 investigate the average travel time to access opportunities and show the statistical significance (t-test at 95% confidence) of different population groups for five- and 10-minute FLM travel times when walking.

White households (the reference case) using the five-minute FLM walking access case average 56.3 minutes, 52.8 minutes, and 34.1 minutes to reach hospital, education, and grocery, respectively. For the 10-minute FLM walking access case, white households average 54.3 minutes, 62.1 minutes, and 39.4 minutes to access hospital, education, and grocery. The Black households and Asian households require significantly higher travel time than white households for the five-minute FLM walking case to access hospitals, education, and grocery even though they experience comparable access to transit as white households. Hispanic households also have similar transit accessibility as white households, but experience significantly higher travel time for hospital and education access.

The previous proportion tests indicate a significantly lower proportion of black households than white households can access transit within 10 minutes when walking. For 10-minute FLM access times, the black population has low accessibility and requires higher travel time for reaching hospital with respect to white households. Only Asian household access to grocery experiences higher travel time than their comparison group when accessing education or grocery.

The disabled population experiences significantly lower access to transit than the not-disabled populations for both the five- and 10-minute walk buffer cases. Despite having low accessibility, they have a similar average time to reach grocery and education facilities, but they need significantly higher travel time to reach a hospital in both cases.

All population groups other than households without a car have longer travel times to hospitals than their comparison population, which indicates that the geographic locations of hospitals may systematically disadvantage these population groups. All of the race and ethnicity population groups also experience some disadvantage when compared to white households when accessing education and grocery.

Table 6.4: Statistical Significance of Different Demographics within Five-minute Walk to Opportunities.

Comparison by t test	Hospital	Education	Grocery
Black households with transit access require significantly higher time than white households	White = 56.3 mins Black = 65.0 mins stat. signif.	White = 52.8 mins Black = 54.5 mins stat. signif.	White = 34.1 mins Black = 35.8 mins stat. signif.
Hispanic households with transit access require significantly higher time than white households	white = 56.3 mins Hispanic = 59.0 mins stat. signif.	White = 52.8 mins Hispanic = 53.9 mins stat. signif.	White = 34.1 mins Hispanic = 34.0 mins not stat. signif.
Asian households with transit access require significantly higher time than white households	White = 56.3 mins Asian = 57.7 mins stat. signif.	White = 52.8 mins Asian=59.2 mins stat. signif.	White = 34.1 mins Asian = 36.8 mins stat. signif.
Households that has at least 1 disable person require significantly higher time than households that does not have any disable person	not disabled = 59.1 mins disabled = 63.7 mins stat. signif.	not disabled = 53.9 mins disabled = 54.6 mins not stat. signif.	not disable = 34.6 mins disabled = 34.9 mins not stat. signif.
Households that does not have any car require significantly higher time than households with at least one car	with car = 60.1 mins without car = 58.2 mins not stat. signif.	with car = 54.3 mins without car = 50.4 mins not stat. signif.	with car = 34.8 mins without car = 33.8 mins not stat. signif.

Table 6.5: Statistical Significance of Different Demographics within 10-minute Walk to Opportunities.

Comparison by t test	Hospital	Education	Grocery
Black households with transit access require significantly higher time than white households	White = 54.3 mins Black = 64.0 mins stat. signif.	White = 62.1 mins Black = 52.0 mins not stat. signif.	White = 39.4 mins Black = 39.4 mins not stat. signif.
Hispanic households with transit access require significantly higher time than white households	white = 54.3 mins Hispanic = 59.0 mins stat. signif.	White = 62.1 mins Hispanic = 51.6 mins not stat. signif.	White = 39.4 mins Hispanic = 38.4 mins not stat. signif.
Asian households with transit access require significantly higher time than white households	White = 54.3 mins Asian = 57.7 mins stat. signif.	White = 62.1 mins Asian=59.6 mins not stat. signif.	White = 39.4 mins Asian = 41.3 mins stat. signif.
Households that has at least 1 disable person require significantly higher time than households that does not have any disable person	not disabled = 57.3 mins disabled = 62.0 mins stat. signif.	not disabled = 53.5 mins disabled = 53.2 mins not stat. signif.	not disable = 39.2 mins disabled = 39.2 mins not stat. signif.
Households that does not have any car require significantly higher time than households with at least one car	with car = 58.2 mins without car = 57.1 mins not stat. signif.	with car = 53.5 mins without car = 48.9 mins not stat. signif.	with car = 39.2 mins without car = 38.3 mins not stat. signif.

6.7.2 BIKE

Tables 6.6 and 6.7 present the average travel time to access opportunities and show the statistical significance (t-test at 95% confidence) of different population groups for the five-minute and 10-minute FLM biking cases. White households using a five-minute bike ride as a FLM alternative average 51.6 minutes, 49.7 minutes, and 32.4 minutes to travel to hospital, education, and grocery stores, respectively. Taking a 10-minute bike ride as a FLM alternative changes the average travel times to hospitals, education, and grocery stores to 50.9 minutes, 49.5 minutes, and 37.5 minutes. For both the five- and 10-minute cases, the black population has a significantly lower proportion of transit accessibility than the white population. The black population also requires significantly more travel time than the white population to go to a hospital in the five- and 10-minute cases, and to grocery stores in the five-minute case. While Asian households have similar transit accessibility as white households, they have significantly higher travel times to a hospital, education, and grocery in both the five- and 10-minute access cases. The Hispanic population has similar transit accessibility opportunities as white households in the five-minute FLM biking case, but they require significantly higher travel time to reach a hospital than white households. In the 10-minute FLM biking case, Hispanic households have substantially lower transit accessibility and experience significantly higher travel times to a hospital than white households.

Households with disabled people have lower accessibility in both the five- and 10-minute FLM biking cases. They also need significantly longer travel time to reach their closest hospital than households without disabled people. Only people without a car seem to experience the same transit system access and travel time compared to people with cars.

All population groups other than households without a car have longer travel times to hospital than their comparison population, which indicates that the geographic locations of hospitals may systematically disadvantage these population groups. Similar to the

walking case, the black and Asian population groups also experience some disadvantage when compared to white households when accessing education and grocery.

Table 6.6: Statistical Significance of Different Demographics within Five-minute Bike to Opportunities

Comparison by t test	Hospital	Education	Grocery
Black households with transit access require significantly higher time than white households	White = 51.6 mins Black = 61. 9 mins stat. signif.	White = 49.7 mins Black = 49. 9 mins not stat. signif.	White = 32.4 mins Black = 33.3 mins stat. signif.
Hispanic households with transit access require significantly higher time than white households	white = 51.6 mins Hispanic = 57.0 mins stat. signif.	White = 49. 7 mins Hispanic = 50.1 mins not stat. signif.	White = 32.4mins Hispanic = 32.0mins not stat. signif.
Asian households with transit access require significantly higher time than white households	White = 51.6 mins Asian = 56.8 mins stat. signif.	White = 49.7 mins Asian= 54. 9 mins stat. signif.	White = 32.4 mins Asian= 35.0 mins stat. signif.
Households that has at least 1 disable person require significantly higher time than households that does not have any disable person	not disabled = 55.1 mins disabled = 60.1 mins stat. signif.	not disabled = 50.1mins disabled = 50.8 mins not stat. signif.	not disabled = 32.6 mins disabled = 32.7 mins not stat. signif.
Households that does not have any car require significantly higher time than households with at least one car	with car = 56.2 mins without car = 54.7 mins not stat. signif.	with car = 50.6 mins without car = 46.35 mins not stat. signif.	with car = 32.8 mins without car = 31.5 mins not stat. signif.

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Table 6.7: Statistical Significance of Different Demographics within 10-minute Bike to Opportunities.

Comparison by t test	Hospital	Education	Grocery
Black households with transit access require significantly higher time than white households	White = 50.9 mins Black = 58.4 mins stat. signif.	White = 49.5 mins Black = 46.0 mins not stat. signif.	White = 37.5 mins Black = 37.1 mins not stat. signif.
Hispanic households with transit access require significantly higher time than white households	White = 50.9 mins Hispanic = 54.7 mins stat. signif.	White = 49.5 mins Hispanic = 46.1 mins not stat. signif.	White = 37.5 mins Hispanic = 36.3 mins not stat. signif.
Asian households with transit access require significantly higher time than white households	White = 50.9 mins Asian= 54.1 mins stat. signif.	White = 49.5 mins Asian= 55.4 mins stat. signif.	White = 37.5 mins Asian= 38.5 mins stat. signif.
Households that has at least 1 disable person require significantly higher time than households that does not have any disable person	not disabled = 53.1 mins disabled = 57.5 mins stat. signif.	not disabled = 48.2 mins disabled = 47.5 mins not stat. signif.	not disabled = 37.1 mins disabled = 37.2 mins not stat. signif.
Households that does not have any car require significantly higher time than households with at least one car	with car = 54.1 mins without car = 52.6 mins not stat. signif.	with car = 48.4 mins without car = 44.0 mins not stat. signif.	with car = 37.2 mins without car = 36.1 mins not stat. signif.

6.7.3 E-SCOOTER

Tables 6.8 and 6.9 provide the average travel time to access opportunities and show the statistical significance (t-test at 95% confidence) of different population groups for the five- and 10-minute FLM e-scooter case. White households using a five-minute e-scooter as a FLM alternative average 47.7 minutes, 47.4 minutes, and 30.7 minutes to travel to hospital, education, and grocery stores, respectively. Taking a 10-minute e-scooter ride as a FLM alternative changes the average travel times to 47.3 minutes, 45.6 minutes, and 36 minutes for hospitals, education, and grocery stores. For both the five- and 10-minute cases, the black population has a significantly lower proportion of transit accessibility than the white population. Also, the black population requires significantly more travel time (58.3 minutes and 53.0 minutes) than the white population to reach a

hospital in the five- and 10-minute cases. Asian households have similar outcomes as the biking FLM alternative cases as they have similar accessibility as white households, but they have significantly higher travel times to a hospital, education, and grocery in both the five- and 10-minute e-scooter FLM cases. For the five-minute e-scooter FLM case, the Hispanic population has similar transit accessibility opportunities as white households, but they require significantly higher travel time to reach a hospital than white households. For the 10-minute FLM e-scooter case, Hispanic households have substantially lower transit accessibility and still encounter significantly higher travel times to reach the nearest hospital.

Households with disabled people have lower transit accessibility for both the five- and 10-minute FLM e-scooter cases. They also require significantly longer travel times to visit their closest hospital than households without disabled people. Like the previous alternatives, people without a car seem to experience similar access and travel times compared to people with cars. However, more accurate results assessing differential access for no car-ownership households may require a more granular geographic scale to capture the location of affordable housing within a block group. Like walking and biking, all population groups other than households without a car have longer travel times to hospital than their comparison population, which indicates that the geographic locations of hospitals may systematically disadvantage these population groups.

Table 6.8: Statistical Significance of Different Demographics within Five-minute E-scooter to Opportunities.

Comparison by t test	Hospital	Education	Grocery
Black households with transit access require significantly higher time than white households	White = 47.7 mins Black = 58.3 mins stat. signif.	White = 47.4 mins Black = 46.1 mins not stat. signif.	White = 30.7 mins Black = 31.1 mins not stat. signif.
Hispanic households with transit access require significantly higher time than white households	White = 47.7 mins Hispanic = 53.0 mins stat. signif.	White = 47.4 mins Hispanic = 46.9 mins not stat. signif.	White = 30.7 mins Hispanic = 30.1 mins not stat. signif.
Asian households with transit access require significantly higher time than white households	White = 47.7 mins Asian= 52.6 mins stat. signif.	White = 47.4 mins Asian= 52.3 mins stat. signif.	White = 30.7 mins Asian= 32.6 mins stat. signif.
Households that has at least 1 disable person require significantly higher time than households that does not have any disable person	not disabled = 51.2 mins disabled = 56.0 mins stat. signif.	not disabled = 47.3 mins disabled = 47.5 mins not stat. signif.	not disabled = 30.7 mins disabled = 30.9 mins not stat. signif.
Households that does not have any car require significantly higher time than households with at least one car	with car = 52.2 mins without car = 51.1 mins not stat. signif.	with car = 47.7 mins without car = 42.8 mins not stat. signif.	with car = 30.9 mins without car = 29.6 mins not stat. signif.

Table 6.9: Statistical Significance of Different Demographics within 10-minute E-scooter to Opportunities.

Comparison by t test	Hospital	Education	Grocery
Black households with transit access require significantly higher time than white households	White = 47.3 mins Black = 53.0 mins stat. signif.	White = 45.6 mins Black = 42.8 mins not stat. signif.	White = 36.0 mins Black = 35.6 mins not stat. signif.
Hispanic households with transit access require significantly higher time than white households	White = 47. 3mins Hispanic = 49.5 mins stat. signif.	White = 45.6 mins Hispanic = 42.3 mins not stat. signif.	White = 36.0 mins Hispanic = 34.9 mins not stat. signif.
Asian households with transit access require significantly higher time than white households	White = 47.3 mins Asian= 49.6 mins stat. signif.	White = 45.6 mins Asian = 51.2 mins stat. signif.	White = 36.0 mins Asian = 36.9 mins stat. signif.
Households that has at least 1 disable person require significantly higher time than households that does not have any disable person	not disabled = 48.7 mins disabled = 52.4 mins stat. signif.	not disabled = 44.5 mins disabled = 44.0 mins not stat. signif.	not disabled = 35.6 mins disabled = 35.8 mins not stat. signif.
Households that does not have any car require significantly higher time than households with at least one car	with car = 49.5 mins without car = 47.9 mins not stat. signif.	with car = 44.7 mins without car = 40.8 mins not stat. signif.	with car = 35.7 mins without car = 34.6 mins not stat. signif.

6.7.4 RIDE HAILING

Tables 6.10 and 6.11 provide the average travel time to access opportunities and show the statistical significance (t-test at 95% confidence) of different population groups for five- and 10-minute FLM ride hailing cases. Using ride hailing for FLM access to transit maximizes transit access, but black and Hispanic households still have significantly lower transit accessibility than white households for the five-minute ride-hailing case. For the five-minute FLM ride hailing case, white households average 21.2 minutes, 19.9 minutes, and 19 minutes to travel to hospital, education, and grocery stores, respectively. Black households need significantly higher travel time to reach the three opportunities of interest while Hispanic households only require significantly higher travel time to reach a hospital. For the 10-minute ride hailing FLM case, white households require 25.1 minutes to reach the three opportunities under investigation. Even though all racial groups have similar accessibility to transit in the 10-minute FLM ride hailing case, the Black, Hispanic, and Asian households need significantly higher travel time to reach all three opportunities (hospital, education and grocery store).

Households with disabled people have lower transit access in both the five- and 10-minute FLM ride hailing cases. They also require significantly longer travel times to reach their closest hospital, education and grocery store than households without disabled people for both five- and 10-minute FLM ride hailing cases. Like previous FLM alternatives, people without a car enjoy similar transit access and travel times compared to people with cars. Like the walking, biking and e-scooter FLM alternatives, all population groups other than households without a car have longer travel times to a hospital than their comparison population, which indicates that the geographic locations of hospitals may systematically disadvantage these population groups. The 10-minute FLM ride hailing case shows a unique scenario, which appears to disadvantage the Black, Hispanic

and Asian populations based on their significantly longer travel times to the investigated opportunities.

Table 6.10: Statistical Significance of Different Demographics within Five-minute Ride to Opportunities

Comparison by t test	Hospital	Education	Grocery
Black households with transit access require significantly higher time than white households	White = 21.2 mins Black = 27.9 mins stat. signif.	White = 19.9 mins Black = 21.4 mins stat. signif.	White = 19.0 mins Black = 20.9 mins stat. signif.
Hispanic households with transit access require significantly higher time than white households	White = 21.2 mins Hispanic = 22.4 mins stat. signif.	White = 19.9 mins Hispanic = 19.7 mins not stat. signif.	White = 19.0 mins Hispanic = 19.3 mins not stat. signif.
Asian households with transit access require significantly higher time than white households	White = 21.2 mins Asian = 20.2 mins not stat. signif.	White = 19.9 mins Asian = 19.6 mins not stat. signif.	White = 19.2 mins Asian = 18.5 mins not stat. signif.
Households that has at least 1 disable person require significantly higher time than households that does not have any disable person	not disabled = 22.6 mins disabled = 25.3 mins stat. signif.	not disabled = 19.9 mins disabled = 21.1 mins stat. signif.	not disabled = 19.3 mins disabled = 20.3 mins stat. signif.
Households that does not have any car require significantly higher time than households with at least one car	with car = 23.3 mins without car = 20.2 mins not stat. signif.	with car = 20.3 mins without car = 18.4 mins not stat. signif.	with car = 19.6 mins without car = 18.2 mins not stat. signif.

Table 6.11 Statistical Significance of Different Demographics within 10-minute Ride to Opportunities

Comparison by t test	Hospital	Education	Grocery
Black households with transit access require significantly higher time than white households	White = 25.1 mins Black = 26.7 mins stat. signif.	White = 25.1 mins Black = 26.7 mins stat. signif.	White = 25.1 mins Black = 26.7 mins stat. signif.
Hispanic households with transit access require significantly higher time than white households	White = 25.1 mins Hispanic = 25.9 mins stat. signif.	White = 25.1 mins Hispanic = 25.9 mins stat. signif.	White = 25.1 mins Hispanic = 25.9 mins stat. signif.
Asian households with transit access require significantly higher time than white households	White = 25.1 mins Asian = 25.4 mins stat. signif.	White = 25.1 mins Asian = 25.4 mins stat. signif.	White = 25.1 mins Asian =25.4 mins stat. signif.
Households that has at least 1 disable person require significantly higher time than households that does not have any disable person	not disabled = 25.7 mins disabled = 26.2 mins stat. signif.	not disabled = 25.6 mins disabled = 26.2 mins stat. signif.	not disabled =25.6mins disabled = 26.2mins stat. signif.
Households that does not have any car require significantly higher time than households with at least one car	with car = 25.8 mins without car =25.2 mins not stat. signif.	with car = 25.8 mins without car = 25.2 mins not stat. signif.	with car = 25.8 mins without car = 25.2 mins not stat. signif.

6.8 AFFORDABILITY PLUS ACCESSIBILITY

6.8.1 Affordability

This study estimates household affordability for individual FLM options in Dallas County. The Dallas Area Rapid Transit (DART) has different fare options to meet passenger needs; however, DART usually charges $2.50 for a single one-way trip and has a reduced price for seniors, persons with disabilities, and students. Day passes regularly cost $6 and AM/PM passes cost $3. A 31-day DART pass costs $96. Though the number of trips made by a household depends on the size of the household and number of employees/children in the household, this study considers that one person from a household uses DART at a regular monthly pass price of $96 to identify minimum

household cost to present the best possible household public transportation affordability scenario. The study considers five FLM alternatives; walking, biking, e-scooter, ride hailing, and ride sharing.

The estimated cost of using each FLM alternative and transit to access opportunities are described in Table 6.12. While walking does not cost anything, the other four FLM alternatives require upfront or ongoing costs. This study considers $140 for an annual average cost of bike with a life expectancy of five years based on $500 for initial bicycle cost. An e-scooter costs $500 with approximately $30 annual maintenance costs (e.g., chain lube, replacing the drive, helmet), which makes the annual average cost $130. The estimated cost of using ride hailing and ride sharing is calculated considering the minimum number of expected annual trips to access opportunities as 500 annual trips. One trip of ride hailing and ridesharing costs on average $7 and $4.50, respectively; therefore, the average cost estimates $3,500 and $2,250 for 500 annual trips assuming ride hailing, or ride sharing is used once per transit ride. Table 6.13 shows the affordability of using each FLM alterative based on household income to access transit.

Table 6.12: Annual Cost of using FLM Alternative to Access Transit

FLM Alternative	Walking ($)	Biking ($)	Scooter ($)	Ride hail ($)	Ride share ($)
Cost of purchase/Use	0	500	500	7/ ride	4.5/ride
Annual Maintenance	0	40	30	0	0
Cost of Annual FLM alternative*	0	140	130	3500	2250
Cost of DART services per year**	1152				
Total annual cost	1152	1292	1282	4652	3402

Table 6.13: Affordability to Access 250 Opportunities Annually.

Income Category	15% travel allowance	Walking	Biking	Scooter	Ride hailing	Ride sharing
Less than $10,000	$1,500	Affordable			Not Affordable	
$10,000 to $14,999	$2,250					
$15,000 to $19,999	$3,000					
$20,000 to $24,999	$3,740				Not Affordable	Affordable
$25,000 to $29,999	$4,500					
$30,000 to $34,999	$5,250				Affordable	
$35,000 to $39,999	$6,000					
$40,000 to $44,999	$6,750					
$45,000 to $49,999	$7,500					
$50,000 to $59,999	$9,000					
$60,000 to $74,999	$11,250					
$75,000 to $99,999	$15,000					
$100,000 to $124,999	$18,740					
$125,000 to $149,999	$22,500					
$150,000 to $199,999	$30,000					
$200,000 or more	$30,000+					

The data on number of annual person trips taken by household by household income is collected from the National Household Travel Survey (NHTS, 2017) to estimate the household cost to access opportunities. The analysis converts the annual number of person trips into annual vehicle trips to accommodate ride hailing by more than one person from a household. The methodology uses the annual number of vehicle trips to calculate the affordability of ride hailing as the FLM alternative to access transit. However, to calculate the affordability of using ride sharing as the FLM alternative to access transit, the analysis uses the annual number of person trips because the trips are charged per person. The study considers a vehicle occupancy factor of 1.7 for all vehicle-to-person conversions (FHWA, 2018). The study creates another more likely use scenario for bike and scooter that increases the number of bikes and scooters per household to two to calculate the affordability of using bike and scooter as FLM alternatives to access transit. The average annual cost of ownership and maintenance of bike and scooter are the same as shown in Table 6.14. Table 6.14 explains the affordability of using each FLM alternative for transit access to opportunities based on the annual person trips taken by household by household income (NHTS, 2017).

Table 6.14: Affordability to Access Opportunities Based on Annual Person Trips.

Income Category	15% travel allowance	annual person trips	Annual vehicle trips	Walking	Biking	Scooter	Ride hailing	Ride sharing
Less than $10,000	$1,500	2214	1302	Not Affordable			Not Affordable	
$10,000 to $14,999	$2,250	2214	1302					
$15,000 to $19,999	$3,000	2477	1457	Affordable				
$20,000 to $24,999	$3,740	2477	1457					
$25,000 to $29,999	$4,500	2756	1621					
$30,000 to $34,999	$5,250	2756	1621					
$35,000 to $39,999	$6,000	2976	1751					
$40,000 to $44,999	$6,750	2976	1751					
$45,000 to $49,999	$7,500	2976	1751					
$50,000 to $59,999	$9,000	3172	1866					
$60,000 to $74,999	$11,250	3172	1866					
$75,000 to $99,999	$15,000	3487	2051					
$100,000 to $124,999	$18,740	4033	2372					
$125,000 to $149,999	$22,500	4033	2372				Affordable	
$150,000 to $199,999	$30,000	4033	2372					
$200,000 or more	$30,000+	4033	2372					

6.8.2 Combining Affordability and Accessibility

Ride sharing and ride hailing significantly increase accessibility; however, all population groups cannot afford this service. Therefore, this study identifies the portions of the county with high access and high affordability based on annual person trips for ride hailing/sharing. Figures 6.10 and 6.11 compare the BGs where more than 95% of the population can access or afford ride hailing/sharing within five minutes to access transit.

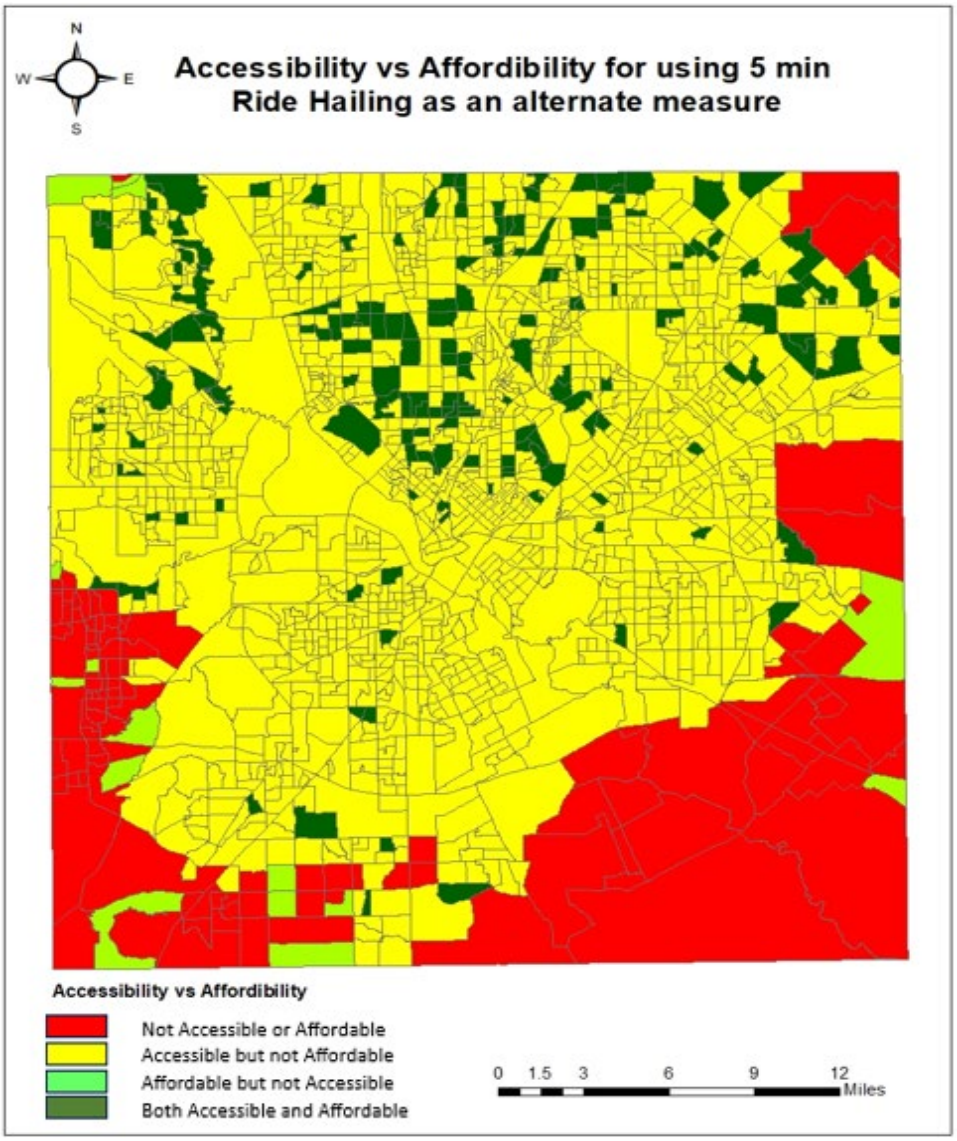

Figure 6.10: Block Groups with More Than 95% of the Population That Can Access or Afford Ride Hailing within Five-minute Buffer

Ride sharing and ride hailing significantly increase accessibility; however, not all the population can access them. Only 9% of BGs have accessibility and affordability for 95% of their population. An astonishing proportion of 82% of the total BGs in Dallas County cannot use transit with the ridesharing option because they are not affordable, while only 1% of BGs are affordable but not accessible to transit due to their long distance to the transit stops. The remaining BGs are not affordable and have no transit access. The lack of affordability means that ride hailing/sharing does not represent a FLM alternative for most transit users within Dallas County, and transit-captive riders seem likely to be those most likely to find this alternative unaffordable.

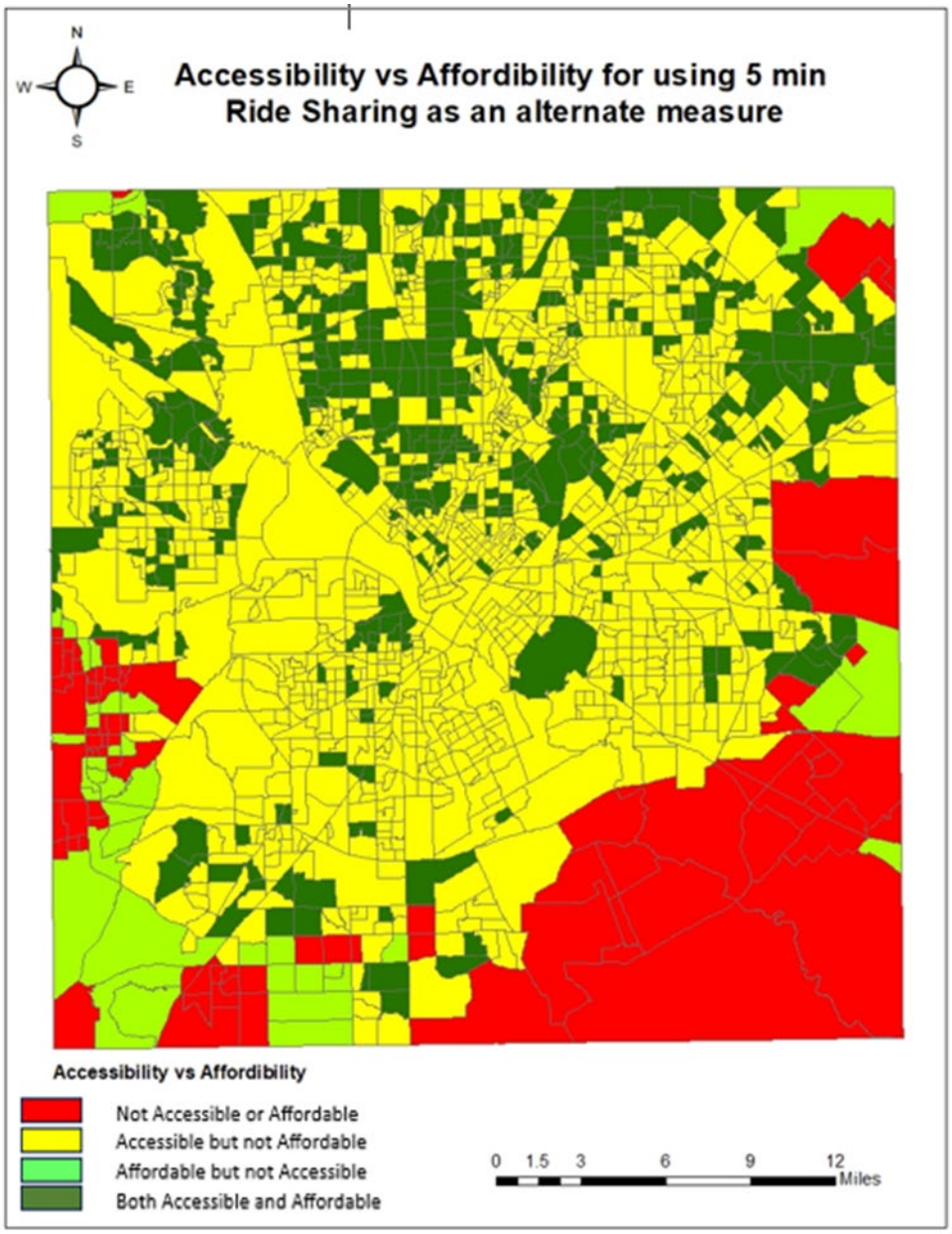

Figure 6.11 Block Groups with More Than 95% of the Population Can Access or Afford Ride Sharing within Five-minute Buffer

Figures 6.12 and 6.13 compare BGs where more than 95% of the population can access or afford ride hailing/sharing within 10 minutes to access transit. Like the five-minute FLM case, ride hailing only serves 95% of BG population for 11% of BGs based on accessibility and affordability. About 73% of BGs cannot afford ride sharing despite having accessibility. The number represents a slight improvement from the five-minute ride hailing case, but still many people cannot afford to use public transportation with ride hailing access. While ride sharing (80%) and ride hailing (72%) can serve a greater percentage of the county population (Table 6.15), e-scooters represent an effective FLM alternative because they serve 69% of the county population. A hybrid solution that

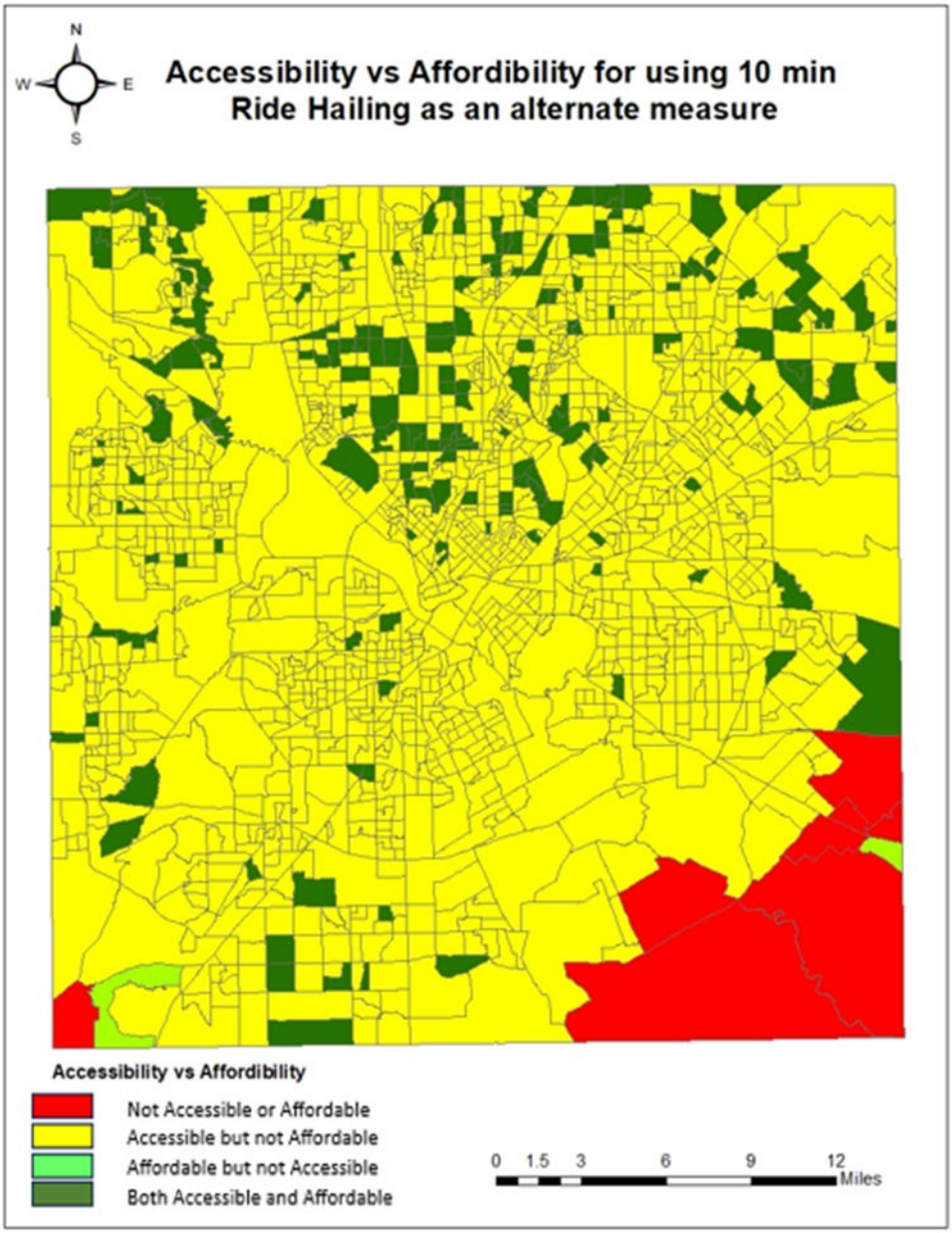

Figure 6.12 Block Groups with More Than 95% of the Population Can Access or Afford Ride Hailing within 10-minute Buffer

emphasizes ride sharing and e-scooters along with improved access infrastructure may be an effective strategy to improve access and affordability for more of the county population. Due to DART's limited service area (member cities) and poverty within Dallas County, 20% of the county population may not have affordable access to public transportation.

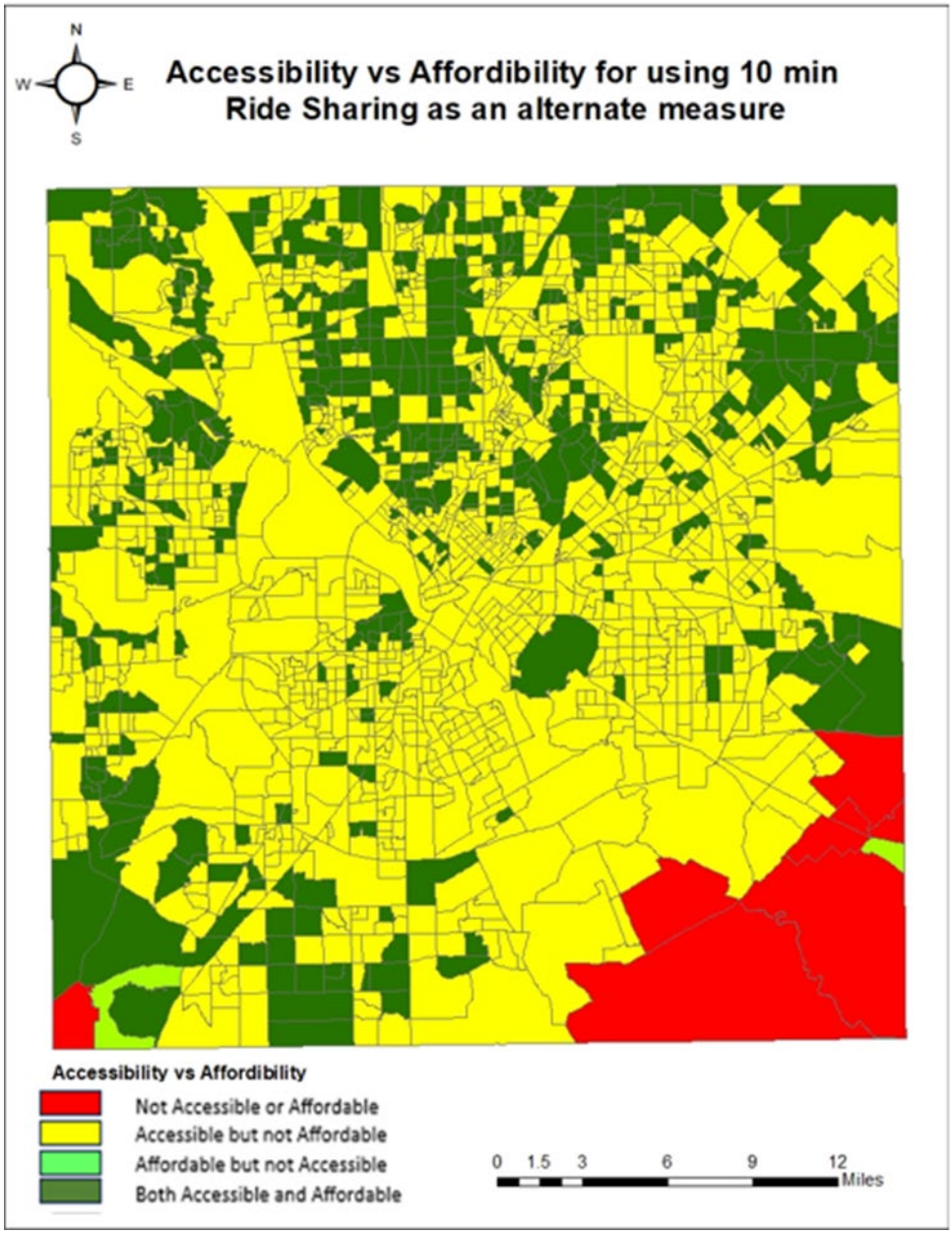

Figure 6.13: Block Groups with More Than 95% of the Population Can Access or Afford Ride Sharing within 10-minute Buffer

Table 6.15: Percentage of Dallas County based on FLM Alternatives within Five-minute Buffer

FLM strategies (5- minute access time)	Type	Number of households	Percentage in Dallas County
Walk	Can Access & Afford	404,919	44%
Bike	Can Access & Afford	597,187	64%
E-scooter	Can Access & Afford	640,095	69%
Ride hailing	Can Afford	714,768	77%
	Can Access & Afford	745,604	72%
Ride sharing	Can Afford	664,377	86%
	Can Access & Afford	800,575	80%

6.9 JOB ACCESSIBILITY

6.9.1 Job Accessibility among Different FLM Methods

Job accessibility represents another critical opportunity for the population to access, but the analysis shifts its focus from the closest opportunity to the total opportunities available within a fixed travel time. The study selects 30 and 60 minutes as the two different time thresholds for job accessibility. Figures 6.14 to 6.15 provide the percentage of Dallas County households with access to different ranges of jobs using walking, biking, e-scooter, and ride hailing for the five- and 10-minute buffers and 30- and 60-minute time thresholds. Walking always has less job accessibility than any other FLM alternative. More than 40% of people have less than 1,000 jobs accessible when they walk to the transit stations and try to reach their work within 30 minutes. This improves if they increase their commute time to 60 minutes, but more than 10% of people still have access to less than 1,000 jobs. This job accessibility increases for bikes and e-scooter, respectively, like other opportunities.

Regardless of buffer type or access time, ride-hailing always provides higher job accessibility. For the lowest access case (five-minute buffer and 30-minute travel time), more than 80% of all households have more than 75,000 jobs accessible if they use ride-hailing. For the same case, the lowest number of jobs accessible by ride hailing (15,000-20,000) exceeds the number of jobs accessible by more than 95% of the households using any of the other alternatives. For the five-minute buffer and 60-minute travel time case, about 5% of households using walking as the FLM alternative, about 8% of households using biking as the FLM alternative, and about 12% of households using e-scooter as the FLM alternative exceed 75,000 jobs accessible, which more than 95% of households using ride hailing as the FLM alternative achieve. Figures 6.16 and 6.17 show that for the 10-minute buffer and 30-minute travel time case, the non-ride hailing alternatives have some (less than 5%) households with access to more than 75,000 jobs, but the ride hailing alternative provides access to more than 75,000 jobs for about 98% of households. For the 10-minute buffer and 60-minute travel time case, the non-ride hailing alternatives increase to between 5% and 9% of households with access to more than 75,000 jobs. The total percentage of households with access to more than 75,000

jobs decreases somewhat because the total number of households with access to transit increases for the 10-minute buffer. The ride hailing alternative now provides access to more than 75,000 jobs for about 100% of households.

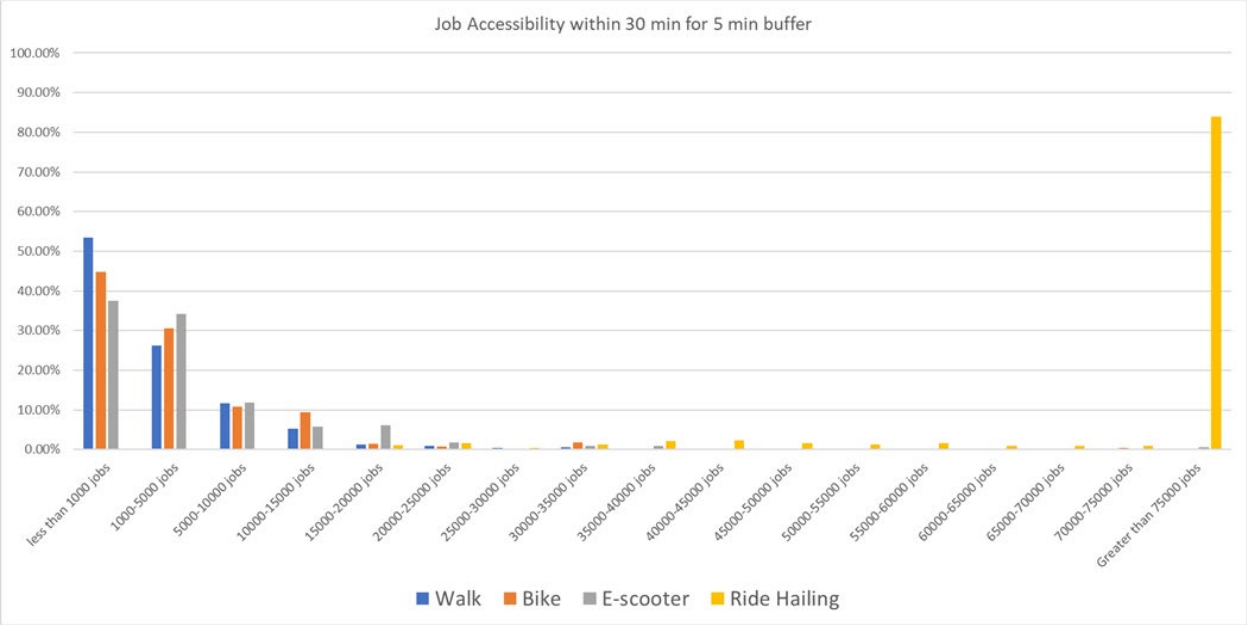

Figure 6.14: Job Accessibility within 30 Minutes for Five-minute Buffer for Different FLM Methods

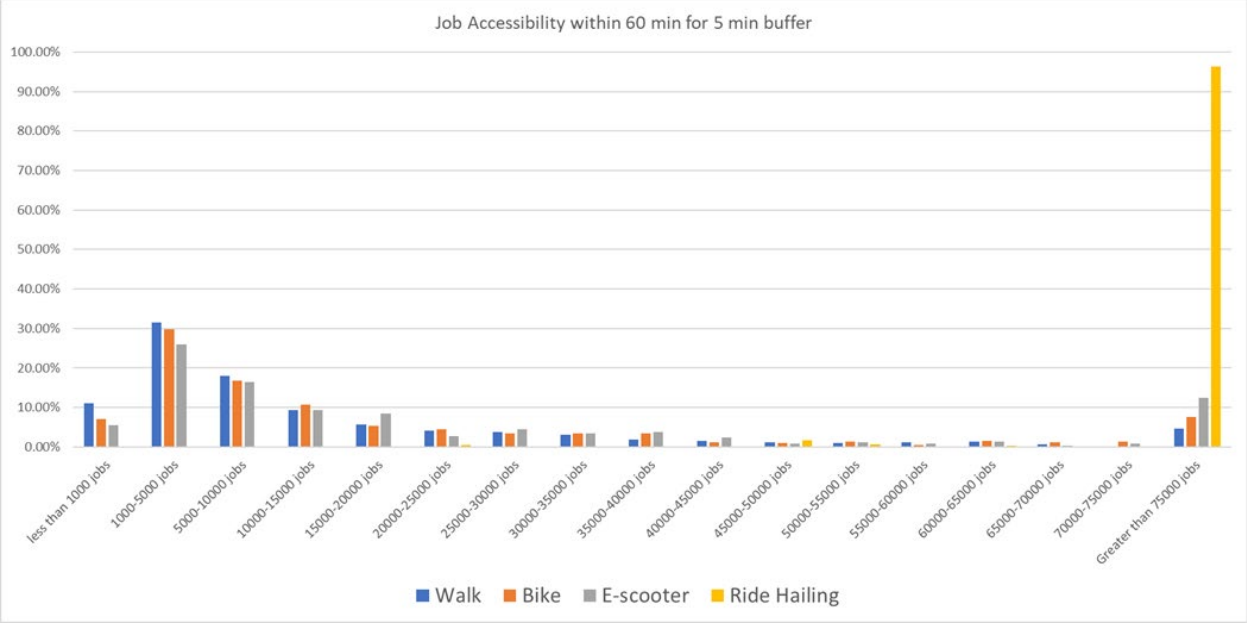

Figure 6.15: Job Accessibility within 60 Minutes for Five-minute Buffer for Different FLM Methods

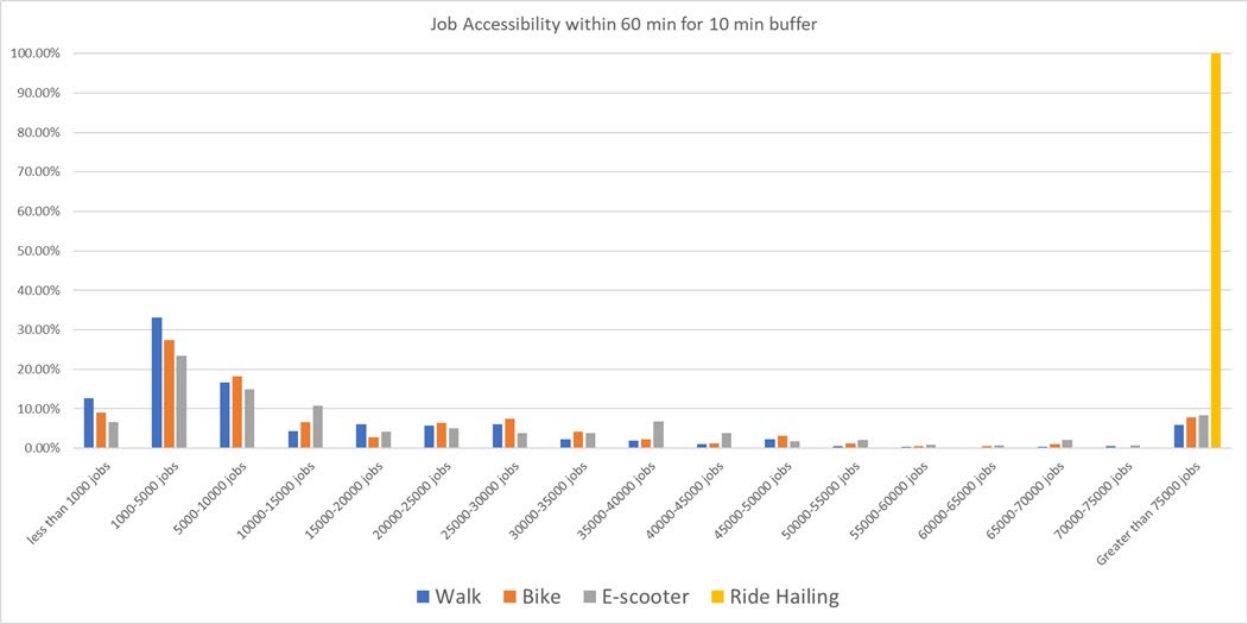

Figure 6.16: Job accessibility within 30 minutes for 10-minute buffer for different FLM methods

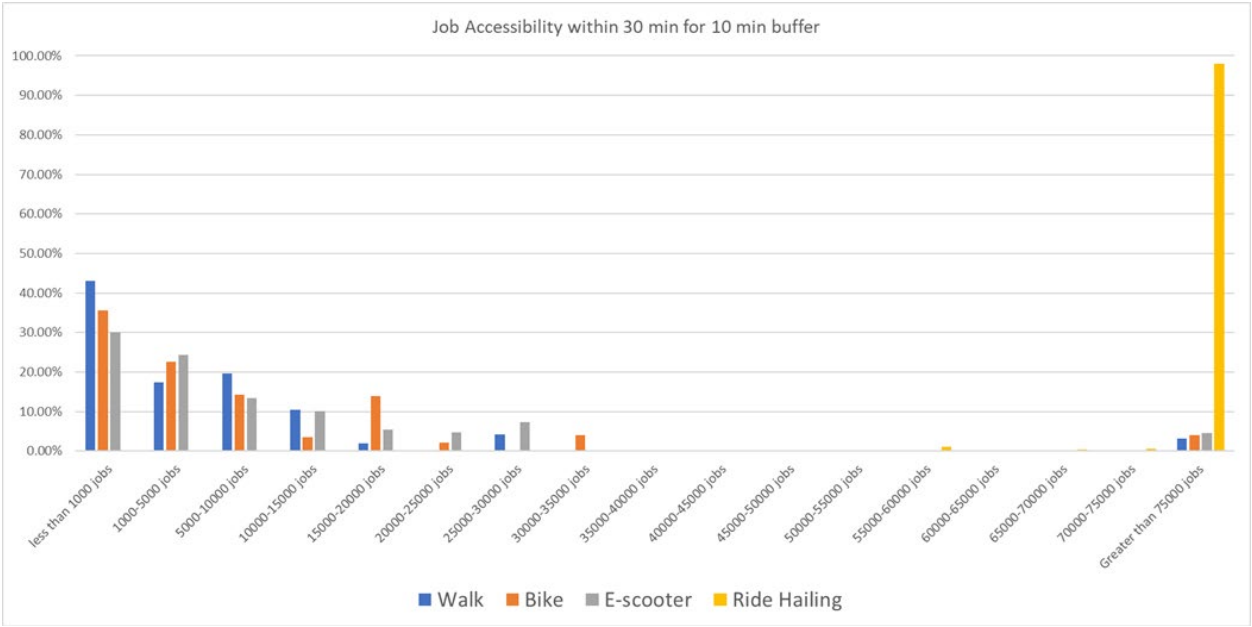

Figure 6.17: Job Accessibility within 60 Minutes for 10-minute Buffers for Different FLM Methods

6.9.2 Job Accessibility among Different Disadvantaged People

Tables 6.16 to 6.23 show the statistical significance of job accessibility among different disadvantaged populations. A significant disparity among racial populations occurs for job accessibility. Regardless of any buffer or accessibility type or time frame, the white population always has significantly higher job accessibility than the Black and Hispanic populations. As most of the low-income population lies within these two racial groups, racially disadvantaged people likely experience much more difficulty finding a job than white people. The Asian community also has lower access to jobs than white households, and it is significantly lower for all 60-minute commute cases except 10-minute FLM ride hailing access. Surprisingly, the only significant difference for the 30-minute commute occurs for five-minute FLM ride hailing access.

Disabled people suffer the same trend as the Black and Hispanic populations. For all the FLM alternatives and travel time thresholds, households with disabled people have significantly less job accessibility than households without disabled people. Households with no car have similar job accessibility as households with a car; therefore, transit dependence does not represent a disadvantage in access to opportunities using public transportation.

Table 6.16: Job Access for the Five-minute Walking Buffer Case

Comparison by t-test	Within 30 min	Within 60 min
Black Households with transit access have significantly lower job accessibility than White households	White= 4148 Black= 2235 Stat. Sign.	White= 22388 Black= 11687 Stat. Sign.
Hispanic Households with transit access have significantly lower job accessibility than White households	White= 4148 Hispanic = 2347 Stat. Sign.	White= 22388 Hispanic = 12450 Stat. Sign.
Asian Households with transit access have significantly lower job accessibility than White households	White= 418 Asian= 3963 Not Stat. Sign.	White= 22388 Asian = 18027 Stat. Sign.
Households with at least 1 disabled person have significantly lower job access than households without any disabled person	Not Disabled= 3342 Disabled= 2130 Stat. Sign.	Not Disabled= 17470 Disabled= 12003 Stat. Sign.
Households without a car have significantly lower job access than households with at least one car	With car= 3099 No car= 3141 Not Stat. Sign.	With car= 16474 No car= 15990 Not Stat. Sign.

Table 6.17: Job Access for the Five-minute Bike Buffer

Comparison by t-test	Within 30 min	Within 60 min
Black Households with transit access have significantly lower job accessibility than White households	White= 5533 Black= 3041 Stat. Sign.	White= 27891 Black= 15360 Stat. Sign.
Hispanic Households with transit access have significantly lower job accessibility than White households	White= 5533 Hispanic = 3030 Stat. Sign.	White= 27891 Hispanic = 16445 Stat. Sign.
Asian Households with transit access have significantly lower job accessibility than White households	White= 5533 Asian = 5349 Not Stat. Sign.	White= 27891 Asian = 22548 Stat. Sign.
Households with at least 1 disabled person have significantly lower job access than households without any disabled person	Not Disabled= 4440 Disabled= 2888 Stat. Sign.	Not Disabled= 22295 Disabled= 15747 Stat. Sign.
Households without a car have significantly lower job access than households with at least one car	With car= 4137 No car= 4096 Not Stat. Sign.	With car= 21066 No car= 20788 Not Stat. Sign.

Table 6.18: Job Access for the Five-minute E-scooter Buffer

Comparison by t-test	Within 30 min	Within 60 min
Black Households with transit access have significantly lower job accessibility than White households	White= 7059 Black= 3884 Stat. Sign.	White= 34134 Black= 19770 Stat. Sign.
Hispanic Households with transit access have significantly lower job accessibility than White households	White= 7059 Hispanic = 3730 Stat. Sign.	White= 34134 Hispanic = 21413 Stat. Sign.
Asian Households with transit access have significantly lower job accessibility than White households	White= 7059 Asian = 6921 Not Stat. Sign.	White= 341334 Asian = 27551 Stat. Sign.
Households with at least 1 disabled person have significantly lower job access than households without any disabled person	Not Disabled= 5633 Disabled= 3668 Stat. Sign.	Not Disabled= 27913 Disabled=20328 Stat. Sign.
Households without a car have significantly lower job access than households with at least one car	With car= 5263 No car= 5059 Not Stat. Sign.	With car= 26440 No car= 26638 Not Stat. Sign.

Table 6.19: Job Access for the Five-minute Ride Hailing Buffer

Comparison by t-test	Within 30 min	Within 60 min
Black Households with transit access have significantly lower job accessibility than White households	White= 359858 Black= 241645 Stat. Sign.	White= 732710 Black= 547283 Stat. Sign.
Hispanic Households with transit access have significantly lower job accessibility than White households	White= 359858 Hispanic = 289287 Stat. Sign.	White= 732710 Hispanic = 636085 Stat. Sign.
Asian Households with transit access have significantly lower job accessibility than White households	White= 359858 Asian = 329524 Stat. Sign.	White= 732710 Asian = 666557 Stat. Sign.
Households with at least 1 disabled person have significantly lower job access than households without any disabled person	Not Disabled= 315705 Disabled= 276627 Stat. Sign.	Not Disabled= 668116 Disabled= 600083 Stat. Sign.
Households without a car have significantly lower job access than households with at least one car	With car= 307455 No car= 315242 Not Stat. Sign.	With car= 652518 No car= 681819 Not Stat. Sign.

Table 6.20: Job Access for the 10-minute Walking Buffer

Comparison by t-test	Within 30 min	Within 60 min
Black Households with transit access have significantly lower job accessibility than White households	White= 11774 Black= 5331 Stat. Sign.	White= 24707 Black= 12634 Stat. Sign.
Hispanic Households with transit access have significantly lower job accessibility than White households	White= 11774 Hispanic = 4527 Stat. Sign.	White= 24707 Hispanic = 13131 Stat. Sign.
Asian Households with transit access have significantly lower job accessibility than White households	White= 11774 Asian= 9607 Not Stat. Sign.	White= 24707 Asian = 21036 Stat. Sign.
Households with at least 1 disabled person have significantly lower job access than households without any disabled person	Not Disabled= 9069 Disabled= 4080 Stat. Sign.	Not Disabled= 19541 Disabled= 12631 Stat. Sign.
Households without a car have significantly lower job access than households with at least one car	With car= 8180 No car= 7250 Not Stat. Sign.	With car= 18250 No car= 16879 Not Stat. Sign.

Table 6.21: Job Access for the 10-minute Bike Buffer

Comparison by t-test	Within 30 min	Within 60 min
Black Households with transit access have significantly lower job accessibility than White households	White= 11774 Black= 5331 Stat. Sign.	White= 32070 Black= 17356 Stat. Sign.
Hispanic Households with transit access have significantly lower job accessibility than White households	White= 11774 Hispanic = 4527 Stat. Sign.	White= 32070 Hispanic = 18212 Stat. Sign.
Asian Households with transit access have significantly lower job accessibility than White households	White= 11774 Asian= 9607 Not Stat. Sign.	White= 32070 Asian = 26846 Stat. Sign.
Households with at least 1 disabled person have significantly lower job access than households without any disabled person	Not Disabled= 9069 Disabled= 4080 Stat. Sign.	Not Disabled= 25710 Disabled= 17710 Stat. Sign.
Households without a car have significantly lower job access than households with at least one car	With car= 8180 No car= 7250 Not Stat. Sign.	With car= 24233 No car= 23484 Not Stat. Sign.

Table 6.22: Job Access for the 10-minute E-scooter Buffer

Comparison by t-test	Within 30 min	Within 60 min
Black Households with transit access have significantly lower job accessibility than White households	White= 18869 Black= 8950 Stat. Sign.	White= 37780 Black= 21216 Stat. Sign.
Hispanic Households with transit access have significantly lower job accessibility than White households	White= 18869 Hispanic = 8014 Stat. Sign.	White= 37780 Hispanic = 22927 Stat. Sign.
Asian Households with transit access have significantly lower job accessibility than White households	White= 18869 Asian= 15573 Not Stat. Sign.	White= 37780 1 Asian = 31066 Stat. Sign.
Households with at least 1 disabled person have significantly lower job access than households without any disabled person	Not Disabled= 14639 Disabled= 7416 Stat. Sign.	Not Disabled= 30667 Disabled= 22564 Stat. Sign.
Households without a car have significantly lower job access than households with at least one car	With car= 13306 No car= 12474 Not Stat. Sign.	With car= 29059 No car= 29728 Not Stat. Sign.

Table 6.23: Job Access for the 10-minute Ride Hailing Buffer

Comparison by t-test	Within 30 min	Within 60 min
Black Households with transit access have significantly lower job accessibility than White households	White= 686010 Black= 549432 Stat. Sign.	White= 1087457 Black= 922495 Stat. Sign.
Hispanic Households with transit access have significantly lower job accessibility than White households	White= 686010 Hispanic = 615567 Stat. Sign.	White= 1087457 Hispanic = 1020073 Stat. Sign.
Asian Households with transit access have significantly lower job accessibility than White households	White= 686010 Asian= 655477 Stat. Sign.	White= 1087457 Asian = 1068411 Not Stat. Sign.
Households with at least 1 disabled person have significantly lower job access than households without any disabled person	Not Disabled= 644172 Disabled= 574300 Stat. Sign.	Not Disabled= 1037703 Disabled= 975453 Stat. Sign.
Households without a car have significantly lower job access than households with at least one car	With car= 626938 No car= 672631 Not Stat. Sign.	With car= 1021551 No car= 1073663 Not Stat. Sign.

7 CONCLUSIONS AND RECOMMENDATIONS

This is a comprehensive study focusing on the transportation needs of disadvantaged populations, particularly the environmental justice (EJ) population, which includes older adults, racial and ethnic minorities, low-income individuals, persons with disabilities, and those with limited English proficiency. The study aims to address the gaps in public transit access that these groups face, which can significantly impact their quality of life by limiting their access to essential services and opportunities.

The study adopts a community-based participatory research (CBPR) approach, involving the community in the research process to ensure accurate representation of the needs and perspectives of the EJ population. This approach helps identify transportation needs from the ground up and develops performance measures to evaluate transit accessibility. A Community Advisory Board (CAB) consisting of transportation experts, social service providers, and community leaders was formed to guide the research process. This board helped in identifying and recruiting participants, reviewing survey and interview questions, and providing iterative feedback throughout the study. The study developed performance measures based on community feedback to evaluate the transit network's access to opportunities. The performance measure topics include access to opportunities, equity analysis, economic viability, sustainability, limited service hours, reliability, safety, security, affordability, assistive services and built environment. These measures help in identifying gaps in the transportation system and prioritizing areas for improvement. A significant barrier for the EJ population is the first and last mile (FLM) issue, where the distance between a transit stops and the destination is too great, making public transit less accessible and practical. The study identifies walking, biking, e-scooters, and ride-hailing as potential FLM strategies. Each of these alternatives offers different levels of accessibility:

Walking: Limited due to the shortest buffer radius but crucial for immediate access around transit stops.

Biking and E-Scooters: Provide better access than walking, with e-scooters showing the best results among non-motorized options.

Ride-Hailing: Offers the most extensive coverage and fastest travel times but is often unaffordable for many EJ populations.

The study emphasized the need for affordable and accessible FLM solutions tailored to the needs of different demographic groups within the EJ population. The study highlighted the importance of shifting transportation planning towards equity by ensuring all community members have access to essential services and opportunities. Spatial analysis techniques were used to identify areas with significant gaps in transit accessibility. This information is crucial for transportation agencies to prioritize investments and improve service delivery to underserved areas.

As a part of future research, a long-term study can be conducted to assess the impact of implemented first-and-last mile (FLM) solutions and other transit improvements on EJ populations. Future work may also pilot the newly developed performance measures in various settings to evaluate their effectiveness and practicality. These pilots would allow researchers to collect feedback from transit agencies and users to refine these measures and ensure they meet the needs of diverse populations. This approach will help investigate the sustained benefits of the performance measures and FLM strategies and areas needing further intervention. This also facilitates expanding the research applications to include diverse geographical areas beyond Dallas County to gain a more comprehensive understanding of transit equity issues and solutions. This can help identify common challenges and successful strategies applicable to various regions. Policy impact analysis can be performed to assess the effectiveness of policies aimed at improving transit accessibility and their socioeconomic impacts on disadvantaged communities. This can include evaluating current policies and proposing new ones to better address the needs of EJ populations.

Future work needs to investigate the capital and operating costs of different FLM strategies, focusing on the affordability and sustainability for users, especially low-income households. Future research should analyze funding mechanisms, including subsidies and public-private partnerships, to support these strategies and greater access for EJ populations. Future applications of these methods need to investigate the potential for interagency collaborations to address gaps in transit services, particularly at city and county borders. Future efforts should also explore successful models of collaboration and propose frameworks for improving coordination among transit agencies.

8 REFERENCES

1. Adorno, G., Fields, N., Cronley, C., Parekh, R. and Magruder, K., 2018. Ageing in a low-density urban city: Transportation mobility as a social equity issue. *Ageing & Society*, *38*(2), pp.296-320.
2. Ahuja, R.K., Ergun, Ö., Orlin, J.B. and Punnen, A.P., 2002. A survey of very large-scale neighborhood search techniques. *Discrete Applied Mathematics*, *123*(1-3), pp.75-102.
3. Aimen, D. and Morris, A., 2012. *Practical approaches for involving traditionally underserved populations in transportation decisionmaking* (No. Project 8-72).
4. Akiyama, T. and Kim, J.K., 2005. Transportation policies for the elderly and disabled in Japan. *International Journal of Urban Sciences*, *9*(2), pp.87-98.
5. Amekudzi, A.A., Smith, M.K., Brodie, S.R., Fischer, J.M. and Ross, C.L., 2012. Impact of environmental justice on transportation: Applying environmental justice maturation model to benchmark progress. *Transportation research record*, *2320*(1), pp.1-9.
6. Anderson, M., 2016. Who relies on public transit in the US? *Pew Research Center*.
7. Archetti, C., Speranza, M. G., & Weyland, D. (2018). On-demand public transportation. *Int. Trans. Oper. Res*.
8. Arcury, T. A., Gesler, W. M., Preisser, J. S., Sherman, J., Spencer, J., & Perin, J. (2005). The effects of geography and spatial behavior on health care utilization among the residents of a rural region. *Health services research*, *40*(1), 135-156.
9. Asia Pacific Tourism Association, APTA 2019. Last accessed on January 31, 2022. https://www.apta.asia/apta2018-1
10. Attanasio, A., Cordeau, J. F., Ghiani, G., & Laporte, G. (2004). Parallel tabu search heuristics for the dynamic multi-vehicle dial-a-ride problem. *Parallel Computing*, *30*(3), 377-387.
11. Baldacci, R., Christofides, N. and Mingozzi, A., 2008. An exact algorithm for the vehicle routing problem based on the set partitioning formulation with additional cuts. *Mathematical Programming*, *115*(2), pp.351-385.
12. Baldacci, R., Mingozzi, A., & Roberti, R. (2011). New route relaxation and pricing strategies for the vehicle routing problem. *Operations research*, *59*(5), 1269-1283..
13. Banister, D., 2008. The sustainable mobility paradigm. *Transport policy*, *15*(2), pp.73-80.
14. Bard, J. F., Kontoravdis, G., & Yu, G. (2002). A branch-and-cut procedure for the vehicle routing problem with time windows. *Transportation Science*, *36*(2), 250-269.
15. Beaudry, A., Laporte, G., Melo, T. and Nickel, S., 2010. Dynamic transportation of patients in hospitals. *OR spectrum*, *32*(1), pp.77-107.
16. Beiler, M.O. and Mohammed, M., 2016. Exploring transportation equity: Development and application of a transportation justice framework. *Transportation research part D: transport and environment*, *47*, pp.285-298.
17. Beimborn, E.A., Greenwald, M.J. and Jin, X., 2003. Accessibility, connectivity, and captivity: impacts on transit choice. *Transportation Research Record*, *1835*(1), pp.1-9.

18. Benenson, I., Martens, K. and Rofé, Y., 2010. Measuring the gap between car and transit accessibility: estimating access using a high-resolution transit network geographic information system. *Transportation research record*, *2144*(1), pp.28-35.
19. Berbeglia, G., Cordeau, J. F., & Laporte, G. (2012). A hybrid tabu search and constraint programming algorithm for the dynamic dial-a-ride problem. *INFORMS Journal on Computing*, *24*(3), 343-355.
20. Bertini, R.L. and El-Geneidy, A., 2003. Using archived data to generate transit performance measures. *Transportation Research Record: Journal of the Transportation Research Board*, *1841*, pp.109-119.
21. Blumenberg, E., & Manville, M. (2004). Beyond the spatial mismatch: Welfare recipients and transportation policy. *Journal of planning literature*, *19*(2), 182-205.
22. Blumer, H., 1969. Fashion: From class differentiation to collective selection. *The sociological quarterly*, *10*(3), pp.275-291.
23. Boarnet, M.G., Giuliano, G., Hou, Y. and Shin, E.J., 2017. First/last mile transit access as an equity planning issue. *Transportation Research Part A: Policy and Practice*, *103*, pp.296-310.
24. Boisjoly, G. and Yengoh, G.T., 2017. Opening the door to social equity: local and participatory approaches to transportation planning in Montreal. *European transport research review*, *9*(3), p.43.
25. Boland, N., Dethridge, J. and Dumitrescu, I., 2006. Accelerated label setting algorithms for the elementary resource constrained shortest path problem. *Operations Research Letters*, *34*(1), pp.58-68.
26. Brodie, S., & Amekudzi-Kennedy, A. (2017). Performance-Based Methodology for Evaluating Equity for Transportation System Users. *Transportation Research Record*, *2605*(1), 83-91.
27. Brake, Jenny, John D. Nelson, and Steve Wright. "Demand responsive transport: towards the emergence of a new market segment." *Journal of Transport Geography* 12, no. 4 (2004): 323-337.
28. Brodie, S. and Amekudzi-Kennedy, A., 2017. Performance-Based Methodology for Evaluating Equity for Transportation System Users. *Transportation Research Record*, *2605*(1), pp.83-91.
29. Bullard, R.D., 2003. Addressing urban transportation equity in the United States. *Fordham Urb. LJ*, *31*, p.1183.
30. Cambridge Systematics. (2000). *A guidebook for performance-based transportation planning* (No. 446). Transportation Research Board.
31. Center for Neighborhood Technology, H + T Methods 2017. Retrieved from https://htaindex.cnt.org/about/HTMethods_2016.pdf
32. Chabrier, A., 2006. Vehicle routing problem with elementary shortest path-based column generation. *Computers & Operations Research*, *33*(10), pp.2972-2990.
33. Chan, K. and Farber, S., 2019. Factors underlying the connections between active transportation and public transit at commuter rail in the Greater Toronto and Hamilton Area. *Transportation*, pp.1-22.

34. Chandra, S. and Quadrifoglio, L., 2013. A model for estimating the optimal cycle length of demand responsive feeder transit services. *Transportation Research Part B: Methodological*, *51*, pp.1-16.
35. leChandra, S., Bari, M.E., Devarasetty, P.C. and Vadali, S., 2013. Accessibility evaluations of feeder transit services. *Transportation Research Part A: Policy and Practice*, *52*, pp.47-63.
36. Chong, Z.J., Qin, B., Bandyopadhyay, T., Wongpiromsarn, T., Rankin, E.S., Ang, M.H., Frazzoli, E., Rus, D., Hsu, D. and Low, K.H., 2011, September. Autonomous personal vehicle for the first-and last-mile transportation services. In *2011 IEEE 5th International Conference on Cybernetics and Intelligent Systems (CIS)* (pp. 253-260). IEEE.
37. Clark, H.M., 2017. Who rides public transit? *Washington, DC: American Public Transportation Association. Retrieved May 3*, p.2018.
38. Clark, K.M., Wen, F., Choi, S. and Hu, H.H., 2013. *Smart Growth, Environmental Justice, and Projected Cancer Risk in Southern California: Case Study in Regional Planning and Health* (No. 13-5324).
39. Clarke, G., & Wright, J. W. (1964). Scheduling of vehicles from a central depot to a number of delivery points. *Operations research*, *12*(4), 568-581.
40. CO (Wilmington Area Planning Council). (2013). 2013 Transportation Equity Report: Environmental justice. Retrieved from http:// www.wilmapco.org/EJ/2013_EJ_T6_Report.pdf
41. Cordeau, J. F., & Laporte, G. (2003). A tabu search heuristic for the static multi-vehicle dial-a-ride problem. *Transportation Research Part B: Methodological*, *37*(6), 579-594.
42. Cordeau, J.F. and Maischberger, M., 2012. A parallel iterated tabu search heuristic for vehicle routing problems. *Computers & Operations Research*, *39*(9), pp.2033-2050.
43. Cordeau, J.F., 2006. A branch-and-cut algorithm for the dial-a-ride problem. *Operations Research*, *54*(3), pp.573-586.
44. Cornwell, E.Y. and Waite, L.J., 2009. Measuring social isolation among older adults using multiple indicators from the NSHAP study. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *64*(suppl_1), pp.i38-i46.
45. Cornwell, E.Y. and Waite, L.J., 2009. Social disconnectedness, perceived isolation, and health among older adults. *Journal of health and social behavior*, *50*(1), pp.31-48.
46. Cozart, A.M., 2016. Transportation Matters: Closing the Chasm between Housing and Transportation to Foster Communities of Opportunity for All. *J. Affordable Hous. & Cmty. Dev. L.*, *25*, p.219.
47. Creswell, J.W., 2007. Five qualitative approaches to inquiry. *Qualitative inquiry and research design: Choosing among five approaches*, *2*, pp.53-80.
48. Crowley, D.F., Shalaby, A.S. and Zarei, H., 2009. Access walking distance, transit use, and transit-oriented development in North York City Center, Toronto, Canada. *Transportation Research Record*, *2110*(1), pp.96-105.

49. Cullen, F.H., Jarvis, J.J. and Ratliff, H.D., 1981. Set partitioning based heuristics for interactive routing. *Networks*, *11*(2), pp.125-143.
50. Daniels, R. and Mulley, C., 2010. Overcoming barriers to implementing flexible transport services in NSW.
51. Dantzig, G. B., & Ramser, J. H. (1959). The truck dispatching problem. *Management science*, *6*(1), 80-91.
52. Dantzig, G. B., & Wolfe, P. (1961). The decomposition algorithm for linear programs. *Econometrica: Journal of the Econometric Society*, 767-778.
53. Daraio, C., Diana, M., Di Costa, F., Leporelli, C., Matteucci, G. and Nastasi, A., 2016. Efficiency and effectiveness in the urban public transport sector: A critical review with directions for future research. *European Journal of Operational Research*, *248*(1), pp.1-20.
54. Desaulniers, G., Desrosiers, J., Solomon, M.M., Soumis, F. and Villeneuve, D., 1998. A unified framework for deterministic time constrained vehicle routing and crew scheduling problems. In *Fleet management and logistics* (pp. 57-93). Springer, Boston, MA.
55. Desaulniers, G., Lessard, F., & Hadjar, A. (2006). Tabu search, generalized k-path inequalities, and partial elementarity for the vehicle routing problem with time windows. *Les Cahiers du GERAD ISSN*, *711*, 2440.
56. Desrochers, M., Desrosiers, J. and Solomon, M., 1992. A new optimization algorithm for the vehicle routing problem with time windows. *Operations research*, *40*(2), pp.342-354.
57. Desrosiers, J., Dumas, Y., & Soumis, F. (1986). A dynamic programming solution of the large-scale single-vehicle dial-a-ride problem with time windows. *American Journal of Mathematical and Management Sciences*, *6*(3-4), 301-325.
58. Desrosiers, J., Dumas, Y., Solomon, M.M. and Soumis, F., 1995. Time constrained routing and scheduling. *Handbooks in operations research and management science*, *8*, pp.35-139.
59. Dial, R.B., 1995. Autonomous dial-a-ride transit introductory overview. *Transportation Research Part C: Emerging Technologies*, *3*(5), pp.261-275.
60. Diana, M. and Dessouky, M.M., 2004. A new regret insertion heuristic for solving large-scale dial-a-ride problems with time windows. *Transportation Research Part B: Methodological*, *38*(6), pp.539-557.
61. Dumas, Y., Desrosiers, J. and Soumis, F., 1991. The pickup and delivery problem with time windows. *European journal of operational research*, *54*(1), pp.7-22.
62. Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of advanced nursing*, *62*(1), 107-115.
63. El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D. and Loong, C., 2016. The cost of equity: Assessing transit accessibility and social disparity using total travel cost. *Transportation Research Part A: Policy and Practice*, *91*, pp.302-316.

64. Elo, S. and Kyngäs, H., 2008. The qualitative content analysis process. *Journal of advanced nursing*, *62*(1), pp.107-115.
65. Falcocchio, J.C., 2004. Performance measures for evaluating transportation systems: Stakeholder perspective. *Transportation research record*, *1895*(1), pp.220-227.
66. Farber, Steven, Benjamin Ritter, and Liwei 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.
67. Federal Highway Administration. 2017. *Environmental justice, Title VI, non-discrimination and equity*. Retrieved from https://www.fhwa.dot.gov/environment/environmental_justice/equity/
68. Feillet, D., Dejax, P., Gendreau, M., & Gueguen, C. (2004). An exact algorithm for the elementary shortest path problem with resource constraints: Application to some vehicle routing problems. *Networks: An International Journal*, *44*(3), 216-229.
69. Feillet, D., Gendreau, M., & Rousseau, L. M. (2007). New refinements for the solution of vehicle routing problems with branch and price. *INFOR: Information Systems and Operational Research*, *45*(4), 239-256.
70. Feo, T.A. and Resende, M.G., 1995. Greedy randomized adaptive search procedures. *Journal of global optimization*, *6*(2), pp.109-133.
71. Ferguson, E.M., Duthie, J., Unnikrishnan, A. and Waller, S.T., 2012. Incorporating equity into the transit frequency-setting problem. *Transportation Research Part A: Policy and Practice*, *46*(1), pp.190-199.
72. Fields, N.L., Miller, V.J., Cronley, C., Hyun, K.K., Mattingly, S.P., Khademi, S., Nargesi, S.R.R. and Williams, J., 2020. Interprofessional collaboration to promote transportation equity for environmental justice populations: A mixed methods study of civil engineers, transportation planners, and social workers' perspectives. *Transportation Research Interdisciplinary Perspectives*, *5*, p.100110.
73. Fisher, M.L., 1994. Optimal solution of vehicle routing problems using minimum k-trees. *Operations research*, *42*(4), pp.626-642.
74. Fisher, M.L., Jörnsten, K.O. and Madsen, O.B., 1997. Vehicle routing with time windows: Two optimization algorithms. *Operations research*, *45*(3), pp.488-492.
75. Fitzpatrick, K., Brewer, M.A. and Turner, S., 2006. Another look at pedestrian walking speed. *Transportation research record*, *1982*(1), pp.21-29.
76. Fol, S. and Gallez, C., 2014. Social inequalities in urban access. *Urban access for the 21st century: finance and governance models for transport infrastructure*, pp.46-86.
77. Forkenbrock, D. J., & Schweitzer, L. A. (1999). Environmental justice in transportation planning. *Journal of the American Planning Association*, *65*(1), 96-112.
78. Foth, N., Manaugh, K. and El-Geneidy, A.M., 2013. Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006. *Journal of transport geography*, *29*, pp.1-10.
79. Fransen, K., Neutens, T., Farber, S., De Maeyer, P., Deruyter, G., & Witlox, F. (2015). Identifying public transport gaps using time-dependent accessibility levels. *Journal of Transport Geography*, *48*, 176-187.

80. Fu, L., 2002. A simulation model for evaluating advanced dial-a-ride paratransit systems. Transportation Research Part A: Policy and Practice, 36(4), pp.291-307.
81. Gélinas, S., Desrochers, M., Desrosiers, J., & Solomon, M. M. (1995). A new branching strategy for time constrained routing problems with application to backhauling. *Annals of Operations Research*, *61*(1), 91-109.
82. Gilmore, P.C. and Gomory, R.E., 1963. A linear programming approach to the cutting stock problem—Part II. *Operations research*, *11*(6), pp.863-888.
83. Golub, A. and Martens, K., 2014. Using principles of justice to assess the modal equity of regional transportation plans. *Journal of Transport Geography*, *41*, pp.10-20.
84. Golub, A., Marcantonio, R.A. and Sanchez, T.W., 2013. Race, space, and struggles for mobility: transportation impacts on African Americans in Oakland and the East Bay. *Urban Geography*, *34*(5), pp.699-728.
85. Grengs, J., 2010. Job accessibility and the modal mismatch in Detroit. *Journal of Transport Geography*, *18*(1), pp.42-54.
86. Gutiérrez-Jarpa, G., Desaulniers, G., Laporte, G. and Marianov, V., 2010. A branch-and-price algorithm for the vehicle routing problem with deliveries, selective pickups and time windows. *European Journal of Operational Research*, *206*(2), pp.341-349.
87. Handy, S., 2008. 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*(2), pp.113-126.
88. Hashimoto, H., Yagiura, M. and Ibaraki, T., 2008. An iterated local search algorithm for the time-dependent vehicle routing problem with time windows. *Discrete Optimization*, *5*(2), pp.434-456.
89. Henderson, T.S., 2006. A Defensive Alliance: The Maritime Provinces and the Turgeon Commission on Transportation, 1948-1951. *Acadiensis*, pp.46-63.
90. Hernández-Pérez, H., & Salazar-González, J. J. (2007). The one-commodity pickup-and-delivery traveling salesman problem: Inequalities and algorithms. *Networks: An International Journal*, *50*(4), 258-272.
91. Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research*, *15*(9), 1277-1288.
92. Ibaraki, T., Imahori, S., Nonobe, K., Sobue, K., Uno, T. and Yagiura, M., 2008. An iterated local search algorithm for the vehicle routing problem with convex time penalty functions. *Discrete Applied Mathematics*, *156*(11), pp.2050-2069.
93. Ihlanfeldt, K.R. and Sjoquist, D.L., 1998. The spatial mismatch hypothesis: a review of recent studies and their implications for welfare reform. *Housing policy debate*, *9*(4), pp.849-892.
94. Ioachim, I., Desrosiers, J., Dumas, Y., Solomon, M.M. and Villeneuve, D., 1995. A request clustering algorithm for door-to-door handicapped transportation. *Transportation science*, *29*(1), pp.63-78.
95. Irnich, S. and Desaulniers, G., 2005. Shortest path problems with resource constraints. In *Column generation* (pp. 33-65). Springer, Boston, MA.

96. Jaw, J. J., Odoni, A. R., Psaraftis, H. N., & Wilson, N. H. (1986). A heuristic algorithm for the multi-vehicle advance request dial-a-ride problem with time windows. *Transportation Research Part B: Methodological*, *20*(3), 243-257.
97. Johnson, B.J. and White, S.S., 2010. Promoting sustainability through transportation infrastructure? Innovation and inertia in the Kansas City metropolitan area. *Journal of urban planning and development*, *136*(4), pp.303-313.
98. Johnston, A. and Ozment, J., 2011. Concentration in the airline industry: evidence of economies of scale?. *Journal of Transportation Management*, *22*(2), p.6.
99. Jones, P. and Lucas, K., 2012. Social impacts and equity issues in transport: an introduction. *Journal of Transport Geography*, *21*.
100. Kallehauge, B., Larsen, J., & Madsen, O. B. (2006). Lagrangian duality applied to the vehicle routing problem with time windows. *Computers & Operations Research*, *33*(5), 1464-1487.
101. Kallehauge, B., Boland, N., & Madsen, O. B. (2007). Path inequalities for the vehicle routing problem with time windows. *Networks: An International Journal*, *49*(4), 273-293. Kain, J.F., 1968. Housing segregation, negro employment, and metropolitan decentralization. *The quarterly journal of economics*, *82*(2), pp.175-197.
102. Kenyon, S., Lyons, G. and Rafferty, J., 2002. Transport and social exclusion: investigating the possibility of promoting inclusion through virtual mobility. *Journal of Transport Geography*, *10*(3), pp.207-219.
103. Kergosien, Y., Lente, C., Piton, D. and Billaut, J.C., 2011. A tabu search heuristic for the dynamic transportation of patients between care units. *European Journal of Operational Research*, *214*(2), pp.442-452.
104. Koenig, J.G., 1980. Indicators of urban accessibility: theory and application. *Transportation*, *9*(2), pp.145-172
105. Kohl, N., Desrosiers, J., Madsen, O.B., Solomon, M.M. and Soumis, F., 1999. 2-path cuts for the vehicle routing problem with time windows. *Transportation Science*, *33*(1), pp.101-116.
106. Kolen, Antoon WJ, A. H. G. Rinnooy Kan, and Harry WJM Trienekens. "Vehicle routing with time windows." *Operations Research* 35.2 (1987): 266-273.
107. Kravetz, D. and Noland, R.B., 2012. Spatial analysis of income disparities in pedestrian safety in northern New Jersey: is there an environmental justice issue?. *Transportation research record*, *2320*(1), pp.10-17.
108. Kumar, S. N., & Panneerselvam, R. (2012). A survey on the vehicle routing problem and its variants.
109. Kuo, P.F., Zeng, X. and Lord, D., 2011, November. Guidelines for choosing hot-spot analysis tools based on data characteristics, network restrictions, and time distributions. In *Proceedings of the 91 Annual Meeting of the Transportation Research Board* (pp. 22-26).
110. Laws, R., Enoch, M.P., Ison, S.G. and Potter, S., 2008. Demand-Responsive Transport schemes in England and Wales and considerations for their future.

111. Laws, R., M. Enoch, S. Ison, and S. Potter. Demand Responsive Transport: A Review of Schemes in England and Wales. Journal of Public Transportation, 2015. https://doi.org/10.5038/2375-0901.12.1.2.
112. Lenstra, J. K., & Kan, A. R. (1979). Computational complexity of discrete optimization problems. In *Annals of discrete mathematics* (Vol. 4, pp. 121-140). Elsevier.
113. Lesh, M.C., 2013. Innovative concepts in first-last mile connections to public transportation. In *Urban public transportation systems 2013* (pp. 63-74).
114. Lim, A. and Zhang, X., 2007. A two-stage heuristic with ejection pools and generalized ejection chains for the vehicle routing problem with time windows. *INFORMS Journal on Computing*, *19*(3), pp.443-457.
115. Lincoln, Y.S. and Guba, E.G., 1990. Judging the quality of case study reports. *Internation Journal of Qualitative Studies in Education*, *3*(1), pp.53-59.
116. Lincoln, Y.S., 1995. Emerging criteria for quality in qualitative and interpretive research. *Qualitative inquiry*, *1*(3), pp.275-289.
117. Litman, T. (2020). Autonomous vehicle implementation predictions: Implications for transport planning.
118. Liu, X.C., Porter, R.J., Zlatkovic, M., Fayyaz, K. and Taylor, J., 2018. *First and Last Mile Assessment for Transit Systems* (No. MPC 18-347).
119. Lourenço, H. R., Martin, O. C., & Stützle, T. (2010). Iterated Local Search: Framework and Applications. M. Gendreau, J.-Y. Potvin, eds., Handbook of Metaheuristics, International Series in Operations Research & Management Science, vol. 146.
120. Lysgaard, J., 2006. Reachability cuts for the vehicle routing problem with time windows. *European Journal of Operational Research*, *175*(1), pp.210-223.
121. Ma, T., Liu, C. and Erdoğan, S., 2015. Bicycle sharing and public transit: does Capital Bikeshare affect Metrorail ridership in Washington, DC?. *Transportation research record*, *2534*(1), pp.1-9.
122. MacDonald, D., Yew, C.P., Arnold, R., Baxter, J., Halvorson, R.K., Kassoff, H., Meyer, M.D., Philmus, K., Price, T.J., Rose, D.R. and Walton, C.M., 2004. *Transportation Performance Measures in Australia, Canada, Japan, and New Zealand* (No. FHWA-PL-05-001).
123. Madsen, O. B., Ravn, H. F., & Rygaard, J. M. (1995). A heuristic algorithm for a dial-a-ride problem with time windows, multiple capacities, and multiple objectives. *Annals of operations Research*, *60*(1), 193-208.
124. Mahmoudi, M. and Zhou, X., 2016. Finding optimal solutions for vehicle routing problem with pickup and delivery services with time windows: A dynamic programming approach based on state–space–time network representations. *Transportation Research Part B: Methodological*, *89*, pp.19-42.
125. Makarewicz, C., Dantzler, P., & Adkins, A. (2020). Another Look at Location Affordability: Understanding the Detailed Effects of Income and Urban Form on Housing and Transportation Expenditures. *Housing Policy Debate*, *30*(6), 1033-1055.

126. Martens, K., 2012. Justice in transport as justice in accessibility: applying Walzer's 'Spheres of Justice'to the transport sector. *Transportation*, *39*(6), pp.1035-1053.
127. Martens, K., Golub, A. and Robinson, G., 2012. 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*(4), pp.684-695.
128. Martin Lindström, M., 2008. Means of transportation to work and overweight and obesity: a population-based study in southern Sweden.
129. Manaugh, K., & El-Geneidy, A. (2012). Who benefits from new transportation infrastructure? Using accessibility measures to evaluate social equity in public transport provision. In *Accessibility Analysis and Transport Planning*. Edward Elgar Publishing.
130. Masson, R., Lehuédé, F. and Péton, O., 2013. An adaptive large neighborhood search for the pickup and delivery problem with transfers. *Transportation Science*, *47*(3), pp.344-355.
131. Mavoa, S., Witten, K., McCreanor, T., & O'sullivan, D. (2012). GIS based destination accessibility via public transit and walking in Auckland, New Zealand. *Journal of transport geography*, *20*(1), 15-22.
132. McCray, T. and Brais, N., 2007. Exploring the role of transportation in fostering social exclusion: The use of GIS to support qualitative data. *Networks and Spatial Economics*, *7*(4), pp.397-412.
133. Meyer, M., 2001. Measuring That Which Cannot Be Measured--At Least According to Conventional Wisdom. In *Transportation Research Board Conference Proceedings* (No. 26).
134. Mirchandani, P.B. and Lucas, D.E., 2004. Integrated transit priority and rail/emergency preemption in real-time traffic adaptive signal control. *Journal of Intelligent Transportation Systems*, *8*(2), pp.101-115.
135. Mintesnot Woldeamanuel and Liza Wright, "Demand-Responsive Transit", in Encyclopedia of Transportation: Social Science and Policy edited by Mark Garrett, SAGE 2014.
136. Mohan, A., Dileep, A., Ajayan, S., Gutjahr, G. and Nedungadi, P., 2019, December. Comparison of Metaheuristics for a Vehicle Routing Problem in a Farming Community. In *Symposium on Machine Learning and Metaheuristics Algorithms, and Applications* (pp. 49-63). Springer, Singapore.
137. Mohl, R.A., 2004. Stop the road: Freeway revolts in American cities. *Journal of Urban History*, *30*(5), pp.674-706.
138. Nagata, Y., 1997. Edge assembly crossover: A high-power genetic algorithm for the traveling salesman problem. In *Proc. of 7th Int. Conf. on Genetic Algorithms, 1997*.
139. Nagata, Y., Bräysy, O. and Dullaert, W., 2010. A penalty-based edge assembly memetic algorithm for the vehicle routing problem with time windows. *Computers & operations research*, *37*(4), pp.724-737.

140. Neven, A., Braekers, K., Declercq, K., Wets, G., Janssens, D. and Bellemans, T., 2015. Assessing the impact of different policy decisions on the resource requirements of a demand responsive transport system for persons with disabilities. *Transport Policy*, *44*, pp.48-57.
141. Owen, A. and Levinson, D.M., 2015. Modeling the commute mode share of transit using continuous accessibility to jobs. *Transportation Research Part A: Policy and Practice*, *74*, pp.110-122.
142. Padberg, M., & Rinaldi, G. (1987). Optimization of a 532-city symmetric traveling salesman problem by branch and cut. *Operations Research Letters*, *6*(1), 1-7.
143. Parragh, Sophie N., Karl F. Doerner, and Richard F. Hartl. "A survey on pickup and delivery problems." *Journal für Betriebswirtschaft* 58.1 (2008): 21-51.
144. Parragh, S.N., Cordeau, J.F., Doerner, K.F. and Hartl, R.F., 2012. Models and algorithms for the heterogeneous dial-a-ride problem with driver-related constraints. *OR spectrum*, *34*(3), pp.593-633.
145. Patton, M.Q., 1999. Enhancing the quality and credibility of qualitative analysis. *Health services research*, *34*(5 Pt 2), p.1189.
146. Pereira, R.H., Schwanen, T. and Banister, D., 2017. Distributive justice and equity in transportation. *Transport reviews*, *37*(2), pp.170-191.
147. Performance Measure Guide, 2009, last accessed on January 31, 2022 https://ofm.wa.gov/sites/default/files/public/legacy/budget/instructions/other/performancemeasureguide.pdf
148. Perry, E.E., Xiao, X. and Manning, R.E., 2015. Barrier or bridge? The role of transportation in national park visitation by racial and ethnic groups. *World Leisure Journal*, *57*(3), pp.173-184.
149. Perry, T.E., 2014. Seasonal variation and homes: Understanding the social experiences of older adults. *Care Management Journals*, *15*(1), pp.3-10.
150. Pickrell, S. and Neumann, L., 2001. Use of performance measures in transportation decision making. In *Transportation Research Board Conference Proceedings* (No. 26).
151. Plouffe, L. and Kalache, A., 2010. Towards global age-friendly cities: determining urban features that promote active aging. *Journal of urban health*, *87*(5), pp.733-739.
152. Proffitt, D.G., Bartholomew, K., Ewing, R. and Miller, H.J., 2019. Accessibility planning in American metropolitan areas: Are we there yet? *Urban Studies*, *56*(1), pp.167-192.
153. Psaraftis, H.N., 1995. Dynamic vehicle routing: Status and prospects. *Annals of operations research*, *61*(1), pp.143-164.
154. Purvis, C.L., 2001. Data and analysis methods for metropolitan-level environmental justice assessment. *Transportation research record*, *1756*(1), pp.15-21.
155. Ramser, G.D.J., 1959. The truck dispatching problem. *Management Science*, *6*(1), pp.80-91.

156. Repoussis, P.P., Tarantilis, C.D. and Ioannou, G., 2009. Arc-guided evolutionary algorithm for the vehicle routing problem with time windows. *IEEE Transactions on Evolutionary Computation*, *13*(3), pp.624-647.
157. Reschovsky, C.A., 2004. *Journey to Work, 2000*. US Department of Commerce, Economics and Statistics Administration, US Census Bureau.
158. Righini, G. and Salani, M., 2006. Symmetry helps: Bounded bi-directional dynamic programming for the elementary shortest path problem with resource constraints. *Discrete Optimization*, *3*(3), pp.255-273.
159. Ropke, S., Cordeau, J.F. and Laporte, G., 2007. Models and branch-and-cut algorithms for pickup and delivery problems with time windows. *Networks: An International Journal*, *49*(4), pp.258-272.
160. Rousseau, L. M., Gendreau, M., Pesant, G., & Focacci, F. (2004). Solving VRPTWs with constraint programming based column generation. *Annals of Operations Research*, *130*(1-4), 199-216.
161. Schilde, M., Doerner, K.F. and Hartl, R.F., 2011. Metaheuristics for the dynamic stochastic dial-a-ride problem with expected return transports. *Computers & operations research*, *38*(12), pp.1719-1730.
162. Schotman, H.R. and Ludden, G.G., 2014, October. DEMAND RESPONSIVE TRANSPORT AS A SOCIAL INNOVATION THE CASE OF SKEWIEL MOBIEL. In *9th International Conference on Design and Emotion 2014: The Colors of Care* (pp. 70-78). Ediciones Uniandes.
163. Schrimpf, G., Schneider, J., Stamm-Wilbrandt, H. and Dueck, G., 2000. Record breaking optimization results using the ruin and recreate principle. *Journal of Computational Physics*, *159*(2), pp.139-171.
164. Seo, S.E., Ohmori, N. and Harata, N., 2013. Effects of household structure and accessibility on travel. *Transportation*, *40*(4), pp.847-865.
165. Sexton, T. R., & Bodin, L. D. (1985). Optimizing single vehicle many-to-many operations with desired delivery times: I. Scheduling. *Transportation Science*, *19*(4), 378-410.
166. Sexton, T. R., & Bodin, L. D. (1985). Optimizing single vehicle many-to-many operations with desired delivery times: II. Routing. *Transportation Science*, *19*(4), 411-435.
167. Shaw, P. (1998, October). Using constraint programming and local search methods to solve vehicle routing problems. In *International conference on principles and practice of constraint programming* (pp. 417-431). Springer, Berlin, Heidelberg.
168. Shen, Q., 2001. A spatial analysis of job openings and access in a US metropolitan area. *Journal of the American Planning Association*, *67*(1), pp.53-68.
169. Soumis, F., Solomon, M.M., Madsen, O.B.G., Kohl, N., Desrosiers, J., 1999. 2-Path Cuts for the Vehicle Routing Problem with Time Windows. Transp. Sci. 33, 101–116. https://doi.org/10.1287/trsc.33.1.101
170. Strauss, A. and Corbin, J., 1998. *Basics of qualitative research techniques*. Thousand Oaks, CA: Sage publications.

171. Taylor, B.D. and Ong, P.M., 1995. Spatial mismatch or automobile mismatch? An examination of race, residence and commuting in US metropolitan areas. *Urban studies*, *32*(9), pp.1453-1473.
172. Tele-Bus Kraków. Vimeo. https://vimeo.com/7450583. Accessed Mar. 30, 2019.
173. The Demand Responsive Transport (Momo-Cow) Bus in Japan. KogaSoftware incorporated company. https://www.youtube.com/watch?v=UhJ6amCctG4. Accessed Mar. 30, 2019.
174. The History of Paratransit. TransitExec. https://transitexec.com/the-history-ofparatransit/. Accessed Mar. 31, 2019.
175. Tian, G., Wei, Y.D. and Li, H., 2017. Effects of accessibility and environmental health risk on housing prices: A case of Salt Lake County, Utah. *Applied Geography*, *89*, pp.12-21.
176. Tomer, A., Kneebone, E., Puentes, R. and Berube, A., 2011. Missed opportunity: Transit and jobs in metropolitan america.
177. Toth, P., & Vigo, D. (Eds.). (2002). *The vehicle routing problem*. Society for Industrial and Applied Mathematics.
178. Toth, P., & Vigo, D. (Eds.). (2014). *Vehicle routing: problems, methods, and applications*. Society for Industrial and Applied Mathematics.
179. U.S. Environmental Protection Agency (EPA), 2019. EJSCREEN Technical Documentation
180. Vidal, T., Crainic, T.G., Gendreau, M. and Prins, C., 2013. A hybrid genetic algorithm with adaptive diversity management for a large class of vehicle routing problems with time-windows. *Computers & operations research*, *40*(1), pp.475-489.
181. Vu, D.M., Hewitt, M., Boland, N. and Savelsbergh, M., 2018. Solving time dependent traveling salesman problems with time windows. *Optimization online*, *6640*.
182. Wachs, M., 2010. Transportation policy, poverty, and sustainability: history and future. *Transportation research record*, *2163*(1), pp.5-12.
183. Wang, H. and Odoni, A., 2016. Approximating the performance of a “last mile” transportation system. *Transportation Science*, *50*(2), pp.659-675.
184. Wang, K. and Woo, M., 2017. The relationship between transit rich neighborhoods and transit ridership: Evidence from the decentralization of poverty. *Applied geography*, *86*, pp.183-196.
185. Wang, R. and Liu, C., 2013. Bicycle-transit integration in the United States, 2001–2009. *Journal of Public Transportation*, *16*(3), p.6.
186. Wright, S., Emele, C.D., Fukumoto, M., Velaga, N.R. and Nelson, J.D., 2014. The design, management and operation of flexible transport systems: Comparison of experience between UK, Japan and India. *Research in Transportation Economics*, *48*, pp.330-338.
187. Wronski, R. Pace Sees Growth of Call-n-Ride Shuttles. Chicago Tribune. https://www.chicagotribune.com/news/ct-xpm-2011-11-04-ct-met-pace-call-n-ride-20111104-story.html. Accessed Mar. 30, 2019.

188. Yajima, M., Sakamoto, K., & Kubota, H. (2013). Efficacy of bus service reorganization utilizing a hub-and-spoke topology and DRT to meet community needs: A case study of Tokigawa town. *IATSS research*, *37*(1), 49-60
189. Yan, X., Levine, J. and Zhao, X., 2019. Integrating ridesourcing services with public transit: An evaluation of traveler responses combining revealed and stated preference data. *Transportation Research Part C: Emerging Technologies*, *105*, pp.683-696.
190. Zellner, M., Massey, D., Shiftan, Y., Levine, J. and Arquero, M., 2016. Overcoming the last-mile problem with transportation and land-use improvements: An agent-based approach. *International Journal of Transportation*, *4*(1), pp.1-26.
Zuo, T., Wei, H. and Chen, N., 2020. Promote transit via hardening first-and-last-mile accessibility: Learned from modeling commuters' transit use. *Transportation Research Part D: Transport and Environment*, *86*, p.102446.

9 Appendices

9.1 APPENDIX-A.: FOCUS GROUP QUESTIONS

Professional/Frontline Workers Focus Group Questions

Introductory Text:

Hello, my name is XX, and I am from The University of Texas at Arlington School of Social Work. The purpose of this Focus Group is to improve our transportation system for individuals who are at heightened risk of transportation disadvantages, such as low income, minority races and ethnicities, people with disabilities and the elderly. Today, we want to hear about your perspectives and insights into improving the transit system in the Dallas/Fort Worth Metroplex in order to maximize transportation equity across the community…

Focus Group Questions:

1. Let us begin by introducing ourselves. Please briefly describe your position, the length of time you have been in your position, and what you do in your job that is related to transportation.
2. What does “transportation disadvantage” mean to you?
3. What do you think we can do to better plan for transportation in our community?
4. Can you identify any barriers to improving fair access to transportation opportunities?
5. What do you all believe is important to closing the gap to equitable transportation?
6. Does anyone in here ever use public transportation?
    a. Why or why not?
    b. If yes, how often? What’s it like?
    c. How about Uber or Lyft?
    d. Would you feel more inclined to use public transportation if the system was different in some way?
        i. Incentives
        ii. Ease of use (number of stops, convenience, comfort, etc.)

9.2 Appendix-B: Interview Questions

Environmental Justice Population Member Interview Questions

Introductory Text:

Hello, my name is XX, and I am from The University of Texas at Arlington School of Social Work. The purpose of this interview is to improve our transportation system for individuals who may have difficulty accessing reliable transportation. Today, we want to hear about your perspectives and insights into improving the transit system in the Dallas/Fort Worth Metroplex in order to maximize access to transportation across the community…

Interview Questions:

1. How often do you use public transportation?
    a. Why or why not?
    b. If yes, how often? What's it like?
    c. When would you consider using transit? Why?
    d. Would you feel more inclined to use public transportation if the system was different in some way?
        i. Incentives,
        ii. Ease of use (Reliability, Location of stops, Frequency, Cost, Comfort, Time (Waiting/Travel), etc.)
2. Have you thought how you get to the transit system to use it? We call these things first/last mile strategies. Is there anything that could be done to make it more convenient for you to get to a transit station or a bus stop?
    a. How do you think first/mile strategies could be improved?
    b. How does first/last mile affect your ability to use public transit?
    c. Does waiting time matter to you?
    d. What is an acceptable walking distance for you?
3. How about ridesharing, like Uber, Lyft, or Via, or car-sharing, like Zip-car? Why or why not?

9.3 Appendix-C: Online Survey

Default Question Block

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TITLE OF PROJECT

Evaluating Improved Transit Connections for Ladders of Opportunity

INTRODUCTION

You are being asked to participate in a research study that explores the impact of transportation barriers and disadvantage on the lives of people who have limited transportation options. Limited transportation options may include not having a reliable vehicle for personal transportation and barriers that prohibit or restrict access to public transportation systems. Your participation in this research is completely voluntary. Refusal to participate or discontinue your participation at any time will involve no penalty or loss of rights to which you are entitled. Please ask if you have any question at any time.

PURPOSE

The specific purpose of this research study is to explore the barriers to accessing transportation among transportation-disadvantaged populations. Data will be collected through surveys.

The results of this study may be published and/or presented at meetings without naming you as a participant; however, the results of the study will only provide a summary of the findings and will not include any information that will identify you as a participant (your name or your position and employer). Additional research studies could evolve from the information you have provided, but your information will not be linked to you in any way; it will be confidential. Although your rights and privacy will be maintained, the School of Social Work at the University of Texas at Arlington (UTA), the Department of Civil Engineering at UTA, the UTA Institutional Review Board (IRB), and personnel to this research have access to the study records. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above. The IRB at UTA has reviewed and approved this study and the information within this consent form. If, in the unlikely event it becomes necessary for the IRB to review your research records, the University of Texas at Arlington will protect the confidentiality of those records to the extent permitted by law. By law, social workers are mandated reported reporters of suspected child and/or elder abuse or neglect. The only exception to confidentiality in this study is if there is a suspicion of abuse or neglect, and the researchers are mandated to report this to the appropriate State agency.

CONTACT FOR QUESTIONS

Questions about this research may be directed to Courtney Cronley at (865) 742-1150. Any questions you may have about your rights as a research participant or a research-related injury may be directed to the Office of Research Administration; Regulatory Services at (817) 272-2105 or regulatoryservices@uta.edu.

CONSENT

By clicking "ACCEPT" below, you confirm that you are 18 years of age or older and have read or had this document read to you. You have been informed about this study's purpose, procedures, possible benefits and risks, and you may print a copy of this form using the "Print" function in your browser. You have been given the opportunity to ask questions before you make a decision regarding your participation, and you have been told that you can ask other questions at any time.

You voluntarily agree to participate in this study. By clicking "ACCEPT" below, you are not waiving any of your legal rights. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

- ○ ACCEPT; I voluntarily agree to participate in this study
- ○ DECLINE; I do not wish to participate in this study

Please tell us your first and last initials, as well as the day of your birth, and the month of your birth. For example, if your name is John Doe and you were born on Jan. 1, you would write: JD0101.

What year were you born?

How do you describe yourself?

- Female
- Male
- Transgender
- Gender Variant/ Non-conforming
- I do not identify as female, male, or transgender (Please specify):

Are you of Hispanic, Latino, or Spanish origin?

- Yes
- No

What is your race? For purposes of this question, persons of Spanish/Hispanic/Latino origin may be of any race.

- White
- Black of African American
- American Indian and Alaska Native
- Asian
- Native Hawaiian and Other Pacific Islander

Multiple ethnicity/ Other (Please specify):

What is your level of education?

- Completed some high school
- High school graduate
- Completed some college
- Associate degree
- Bachelor's degree
- Completed some postgraduate
- Master's degree
- Ph.D., law or medical degree
- Other advanced degree beyond a Master's degree

Which of the following best describes your employment status?

- Employed, working 40 or more hours per week
- Employed, working 1-39 hours per week
- Not employed, looking for work
- Not employed, NOT looking for work
- Student
- Homemaker
- Retired
- Disabled, not able to work

How long have you been at your current employment?

What degrees, if any, do you have? (For example, a Bachelors and Masters of Social Work).

What licensures do you have related to your employment or degree? (For example, Licensed Master Social Worker).

Transportation Questions

Briefly describe what aspect of your job is related to or affected by transportation:

To what extent do you feel transportation is a problem for lower-income individuals?

- Always a problem
- Frequently a problem
- Occasionally a problem
- Rarely a problem
- Never a problem
- Do not feel qualified to answer

Does your organization provide any transportation resources to lower-income and/or transportation-disadvantaged individuals, e.g. bus passes, etc.?

- Yes
- No
- Not applicable

What transportation services does your organization provide?

- Shuttle service
- Bus passes/vouchers
- Other

To what extent do you think that the following factors affect individuals' abilities to use public transit:

	Does not affect use	May affect use	Definitely affects use	Do not know
Cost of public transit				
Poor connections or transfers				
Knowing how to ride the bus/train				
Limited hours of operation				
Perceived safety on public transit				
Affordability				
Waiting time				
Lack of other transportation options				
Walking distance to and from bus stop/train station				
Other (Please specify)				

What do you think is the number one transportation obstacle for lower-income individuals?

How frequently do you recommend ride-sharing services (e.g., Uber, Lyft, Via) for clients?

- Never
- Once or twice

- Occasionally
- Often
- All the time
- Not applicable
- Do not know about ride-sharing services

Why don't you recommend ride-sharing services for clients (check all that apply)?

- Too expensive for my clients
- Clients do not own cell phones
- Clients would not feel comfortable using these services
- Do not know about these services

To what extent do you think that ride-sharing services (e.g., Uber, Lyft, Via) may improve transportation accessibility for lower-income and transportation disadvantaged individuals?

- Will not improve access at all
- Will not make much of a difference
- May improve access a little
- Will improve access greatly
- Do not know/not familiar with these services

How frequently do you recommend car-sharing services (e.g., Zip-car) for clients?

- Never
- Once or twice
- Occassionally
- Often
- All the time
- Not applicable
- Do not know about car-sharing services

Why don't you recommend car-sharing (e.g., Zip-car) services for clients (check all that apply)?

- Too expensive for my clients
- Clients would feel uncomfortable for my clients
- Do not know about these services

To what extent do you think that car-sharing (e.g., Zip-car) services may improve transportation accessibility for lower-income and transportation disadvantaged individuals?

- Will not improve access at all
- Will not make much of a difference
- May improve access a little
- Will improve access greatly
- Do not know about these services

9.4 Appendix-D: PMs based on SOP (National Transit Agencies)

Performance measures utilizing by different transit agencies in the US

Transit Agency	PMs Categories	Performance Measure
PART	Cost Effectiveness/Efficiency	Cost Recovery Ratio
PART	Cost Effectiveness/Efficiency	Operating Cost Per Unlinked Passenger Trip
Spokane Transit	Cost Effectiveness/Efficiency	Service Effectiveness (Passengers/ Revenue Hour)
PART	Cost Effectiveness/Efficiency	Subsidy Per Passenger Trip
PART	Cost Effectiveness/Efficiency	Unlinked Passenger Trips Per Vehicle Revenue Mile
BRATS	Cost Effectiveness/Efficiency	Admin Cost… (Budget/Balance)
BRATS	Cost Effectiveness/Efficiency	Average Fare… (Florida Peer Financial Comparisons)
APTA	Cost Effectiveness/Efficiency	Cost Efficiency Report to the Legislature
FAST	Cost Effectiveness/Efficiency	Cost efficiency... (Financial/Cost Efficiency)
BRATS	Cost Effectiveness/Efficiency	Cost per Hour… (General Peer Indicators)
BRATS	Cost Effectiveness/Efficiency	Cost Per Hour… (Performance)
RTD	Cost Effectiveness/Efficiency	Cost Per Mile
MTA	Cost Effectiveness/Efficiency	Cost per passenger
FRTS	Cost Effectiveness/Efficiency	Cost per Pass-Trip… (Financial Efficiency)
RTD	Cost Effectiveness/Efficiency	Cost Per Trip
BRATS	Cost Effectiveness/Efficiency	Cost per Trip… (General Peer Indicators)
BRATS	Cost Effectiveness/Efficiency	Cost Per Trip… (Performance)
FRTS	Cost Effectiveness/Efficiency	Cost per Veh-Hour… (Financial Efficiency)
MTA	Cost Effectiveness/Efficiency	Cost per vehicle hour
FRTS	Cost Effectiveness/Efficiency	Cost/Revenue-Hour
City of Seattle	Cost Effectiveness/Efficiency	Cost/Rider
FRTS	Cost Effectiveness/Efficiency	Cost/Trip
MTA	Cost Effectiveness/Efficiency	Fare recovery ratio
FAST	Cost Effectiveness/Efficiency	Fare recovery... (Financial/Cost Efficiency)

Cont'd Performance measures utilizing by different transit agencies in the US

Transit Agency	PMs Categories	Performance Measure
KCATA	Cost Effectiveness/Efficiency	fare box Recovery Ratio
KCATA	Cost Effectiveness/Efficiency	Metro Expense/Mile
BRATS	Cost Effectiveness/Efficiency	Miles Per Gallon… (Effectiveness)
RTD	Cost Effectiveness/Efficiency	Monthly Expenditures
MTA	Cost Effectiveness/Efficiency	Net cost per passenger
City of Seattle	Cost Effectiveness/Efficiency	O&M Cost
FRTS	Cost Effectiveness/Efficiency	Operating Cost... (Breckenridge Transit)
City of Seattle	Cost Effectiveness/Efficiency	Operating Cost/New Ride
BRATS	Cost Effectiveness/Efficiency	Operating Cost… (Budget/Balance)
Lebanon Transit	Cost Effectiveness/Efficiency	Operating Expenses per Passenger Mile…
Lebanon Transit	Cost Effectiveness/Efficiency	Operating Expenses per Unlinked Passenger Trip…
Lebanon Transit	Cost Effectiveness/Efficiency	Operating Expenses per Vehicle Revenue Hour…
Lebanon Transit	Cost Effectiveness/Efficiency	Operating Expenses per Vehicle Revenue Mile…
FAST	Cost Effectiveness/Efficiency	Passengers / vehicle revenue hour (VRH)... (Service)
City of Seattle	Cost Effectiveness/Efficiency	RapidRide Initial Investment Level
BRATS	Cost Effectiveness/Efficiency	Revenue… (Budget/Balance)
FRTS	Cost Effectiveness/Efficiency	Revenue-Hours and Miles
FRTS	Cost Effectiveness/Efficiency	Subsidy/Trip
BRATS	Cost Effectiveness/Efficiency	Total Cost… (Budget/Balance)
BRATS	Cost Effectiveness/Efficiency	Total Operating Expense… (General Peer Indicators)
PART	Cost Effectiveness/Efficiency	Unlinked Passenger Trips Per Vehicle Revenue Hour
RTD	Customer focus/Community	Complaints
RTD	Customer focus/Community	Customer Relations:
FAST	Customer focus/Community	Advocacy... (Community/Environment)
Transit Agency	PMs Categories	Performance Measure
MATA	Customer focus/Community	Average Customer Call Wait Time…
HCM	Customer focus/Community	CBD of 5-million-plus metro area (yes/no)
Spokane Transit	Customer focus/Community	Customer Security
FAST	Customer focus/Community	Feedback… (Customer Focus)
FAST	Customer focus/Community	Paratransit denials... (Service)
FAST	Customer focus/Community	Planning… (Customer Focus)
FAST	Customer focus/Community	Response to complaints… (Customer Focus)
FAST	Customer focus/Community	Road Calls... (Service)
FRTS	Customer focus/Community	Service/Road Calls

HCM	Operation	Dwell time (s)
BRATS	Operation	Headway… (Peer General Service Comparisons)
BRATS	Operation	Hourly Utilization… (Performance)
BRATS	Operation	Hours/Day… (Peer General Service Comparisons)
FAST	Operation	Load factor3... (Ridership)
BRATS	Operation	Mileage Utilization… (Performance)
HCM	Operation	Motorized vehicle running time (s)
FRTS	Operation	One-Way Passenger-Trips
KCATA	Operation	On-time Performance
MATA	Operation	On-time Performance by mode… (Reliability/Quality)
FAST	Operation	On-time performance... (Service)
BRATS	Operation	Operations Recovery… (Performance)
HCM	Operation	Passenger load factor (p/seat)
BRATS	Operation	Passenger Miles/Trip… (Performance)
MTA	Operation	Passenger trips per capita
BRATS	Operation	Passenger Trips… (General Peer Indicators)

Cont'd Performance measures utilizing by different transit agencies in the US

Transit Agency	PMs Categories	Performance Measure
FRTS	Operation	Passenger-Miles
MTA	Operation	Passengers per vehicle hour
FRTS	Operation	Passengers/Hour
FRTS	Operation	Passengers/Mile
FRTS	Operation	Pass-Trips per Hour… (Operating Effectiveness)
FRTS	Operation	Pass-Trips per Mile… (Operating Effectiveness)
BRATS	Operation	Peak Vehicles… (Peer General Service Comparisons)
HCM	Operation	Reentry delay (s/veh)
City of Seattle	Operation	Ridership
Spokane Transit	Operation	Ridership
FAST	Operation	Ridership growth... (Ridership)
RTD	Operation	Ridership, All Funded Routes
RTD	Operation	Ridership, NCRTD Operated Routes
FRTS	Operation	Ridership... (Breckenridge Transit)
APTA	Operation	Roundabout volume-to-capacity ratio (decimal)
MTA	Operation	Service hours per capita
BRATS	Operation	Service Hours/Trip… (Demand)
BRATS	Operation	Service Miles/ Passenger… (Supply)
BRATS	Operation	Total Trips… (Demand)
HCM	Operation	Traffic signal cycle length (s)
HCM	Operation	Transit frequency (veh/h)
RTD	Operation	Vehicle Back Up Ratio
BRATS	Operation	Vehicle Hours… (General Peer Indicators)
BRATS	Operation	Vehicle Hours… (Supply)
BRATS	Operation	Vehicle Miles… (Supply)

Cont'd Performance measures utilizing by different transit agencies in the US

Transit Agency	PMs Categories	Performance Measure
FRTS	Operation	Vehicle-Hours... (Breckenridge Transit)
FRTS	Operation	Vehicle-Miles... (Breckenridge Transit)
FRTS	Operation	Vehicle-Miles/Service Area
BRATS	Operation	Vehicles Fleet… (General Peer Indicators)
MATA	Safety and Security	Accidents per 100,000 miles by mode…
RTD	Safety and Security	Accidents, Major/Minor Tracking
FRTS	Safety and Security	Accidents/1,000 miles
RTD	Safety and Security	Incidents
KCATA	Safety and Security	Passenger Boarding's per Customer Complaint
MATA	Safety and Security	Passenger Complaints per 100,000 miles…
MATA	Safety and Security	Preventable Accidents per 100,000 miles mode…
FAST	Safety and Security	Preventable accidents... (Service)
KCATA	Safety and Security	Vehicle Accidents/Million Miles
BRATS	Service quality	Density… (General Peer Indicators)
HCM	Service quality	Express wait time (min)
FAST	Service quality	Missed fixed route trips... (Service)
HCM	Service quality	Pedestrian LOS score for link (decimal)
HCM	Service quality	Proportion of transit stops with benches (decimal)
HCM	Service quality	Proportion of transit stops with shelters (decimal)
Spokane Transit	Service quality	Public Outreach
BRATS	Service quality	Seats Available… (Effectiveness)
FTA	Service quality	The percentage of facilities
MATA	Service quality	Transit Boarding's by mode… (Ridership/Efficiency)
HCM	Service quality	Transit stop location (nearside/other)
HCM	Service quality	Transit stop position (on-line/off-line)

9.5 APPENDIX-E: BUFFER MAPS

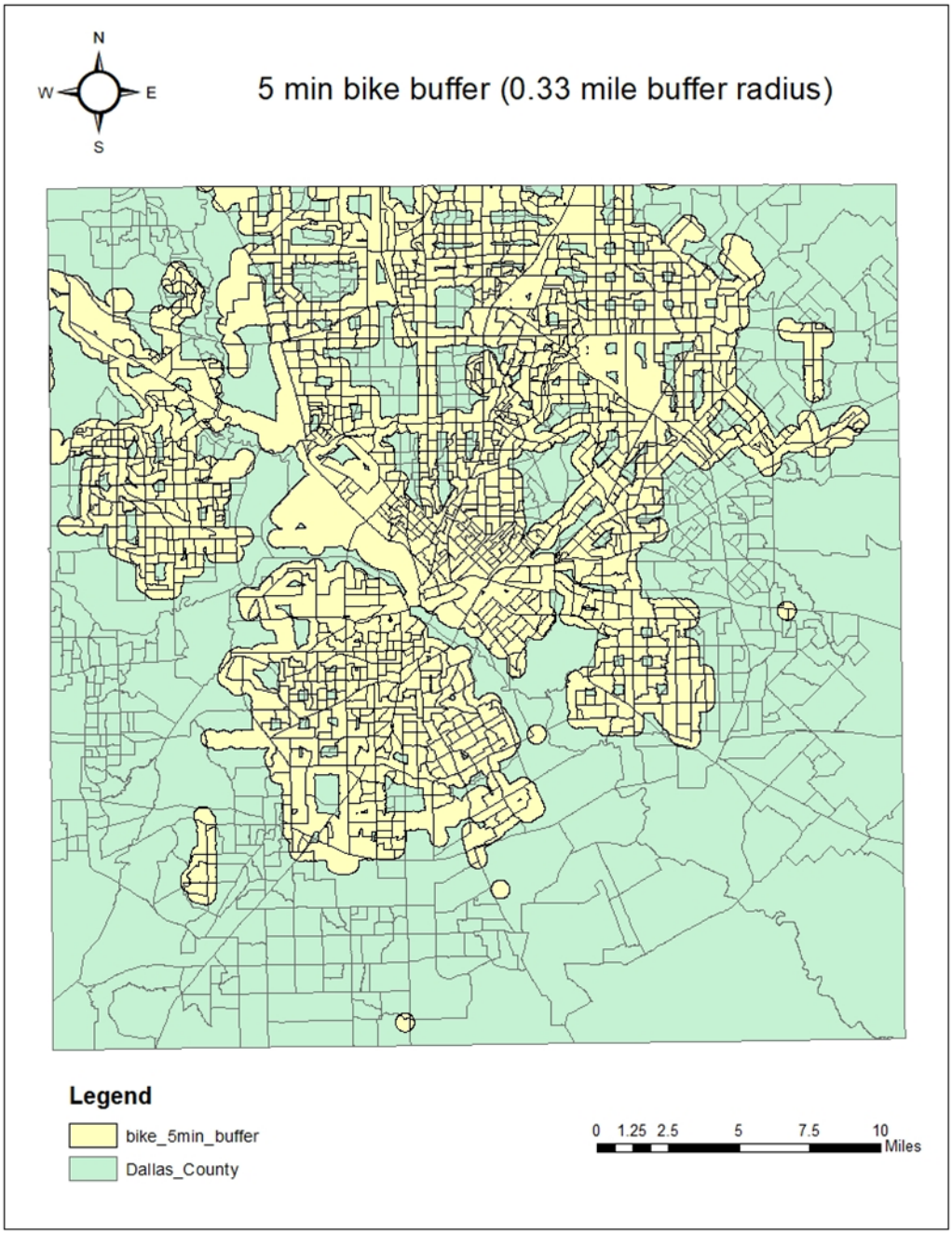

Figure 9.1: 5 min FLM bike travel time for 0.33-mile buffer radius

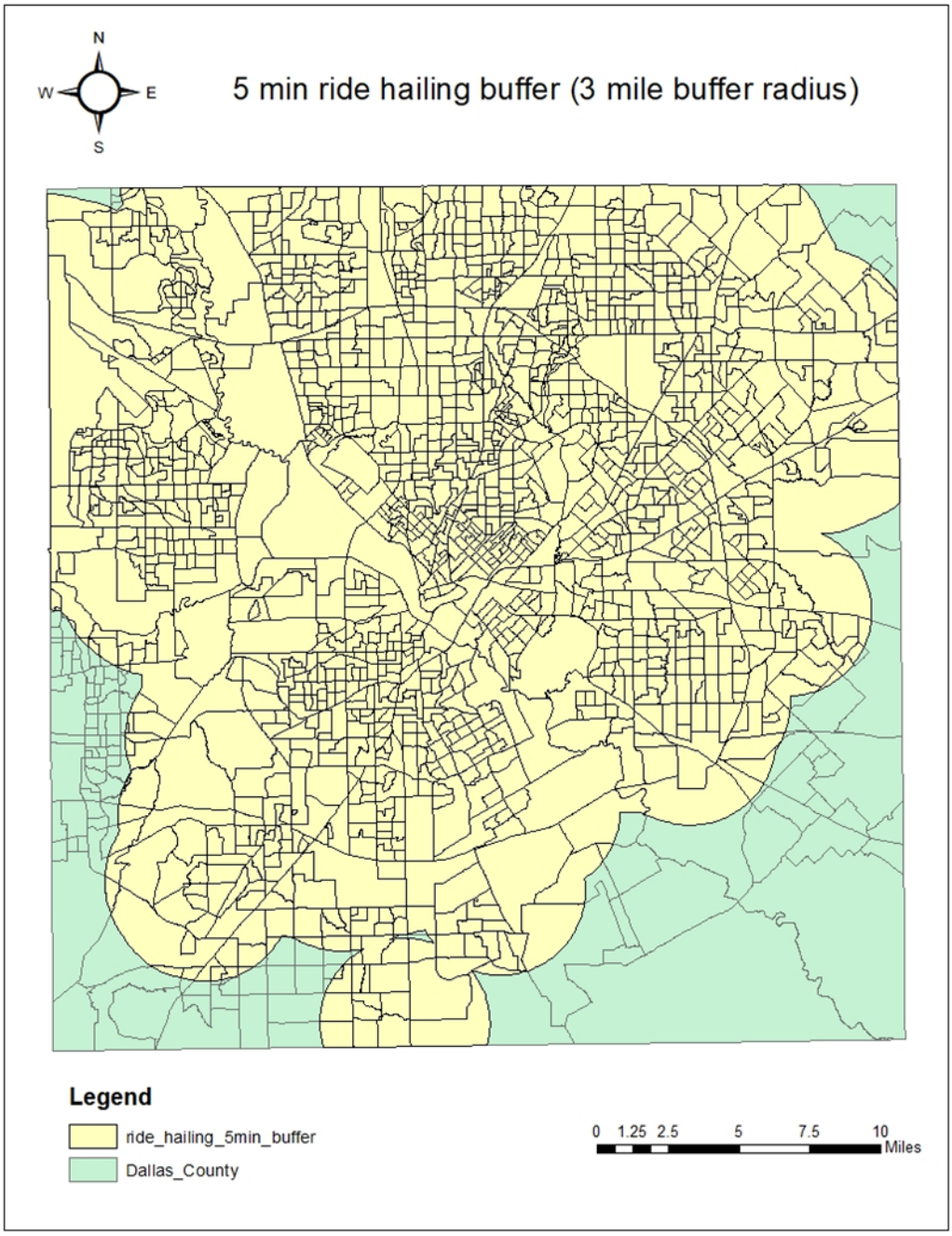

Figure 9.2 5-min FLM ride hailing travel time for 3-mile buffer radius

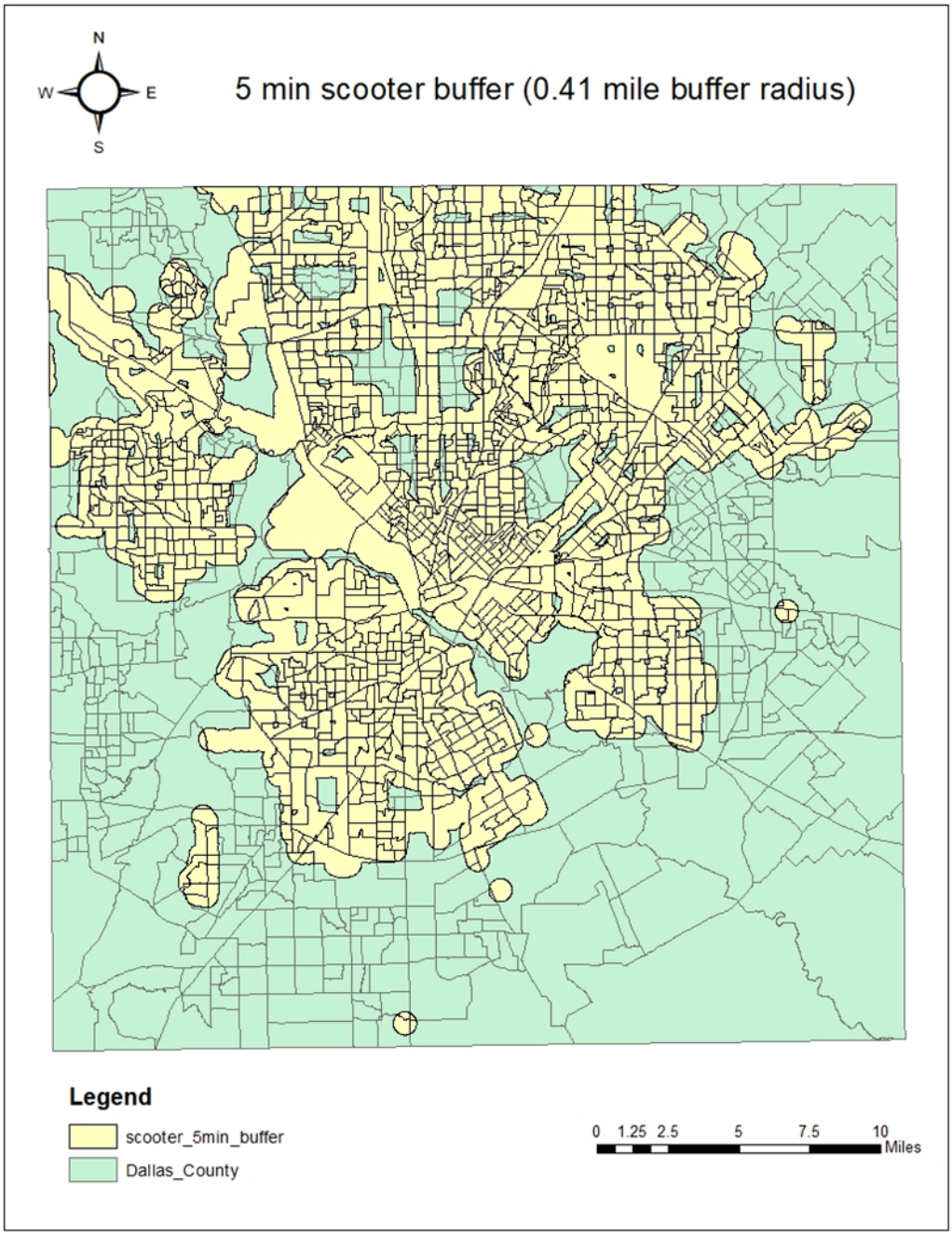

Figure 9.3: 5-min FLM scooter travel time for 0.41-mile buffer radius

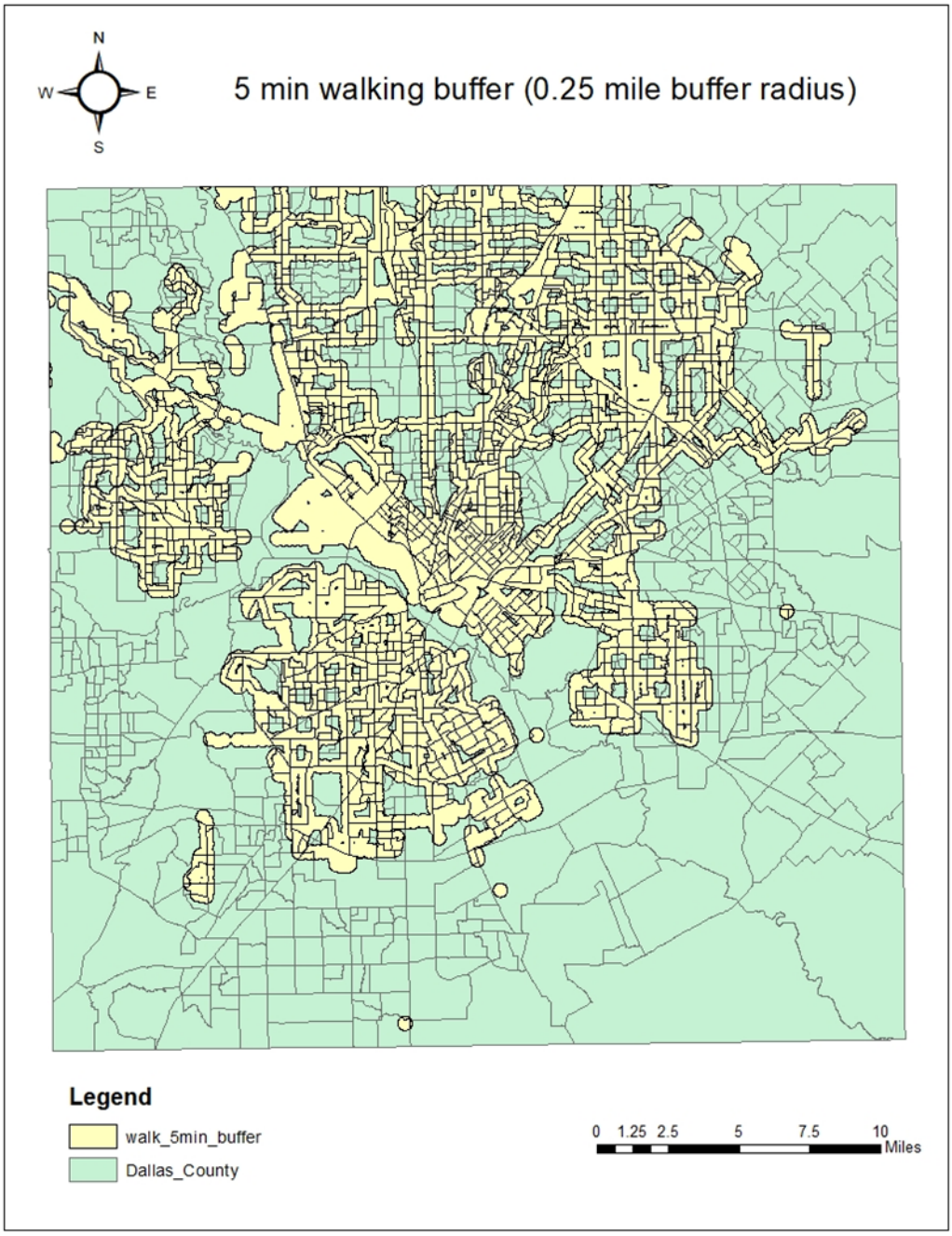

Figure 9.3: 5 min FLM walk travel time for 0.25-mile buffer radius

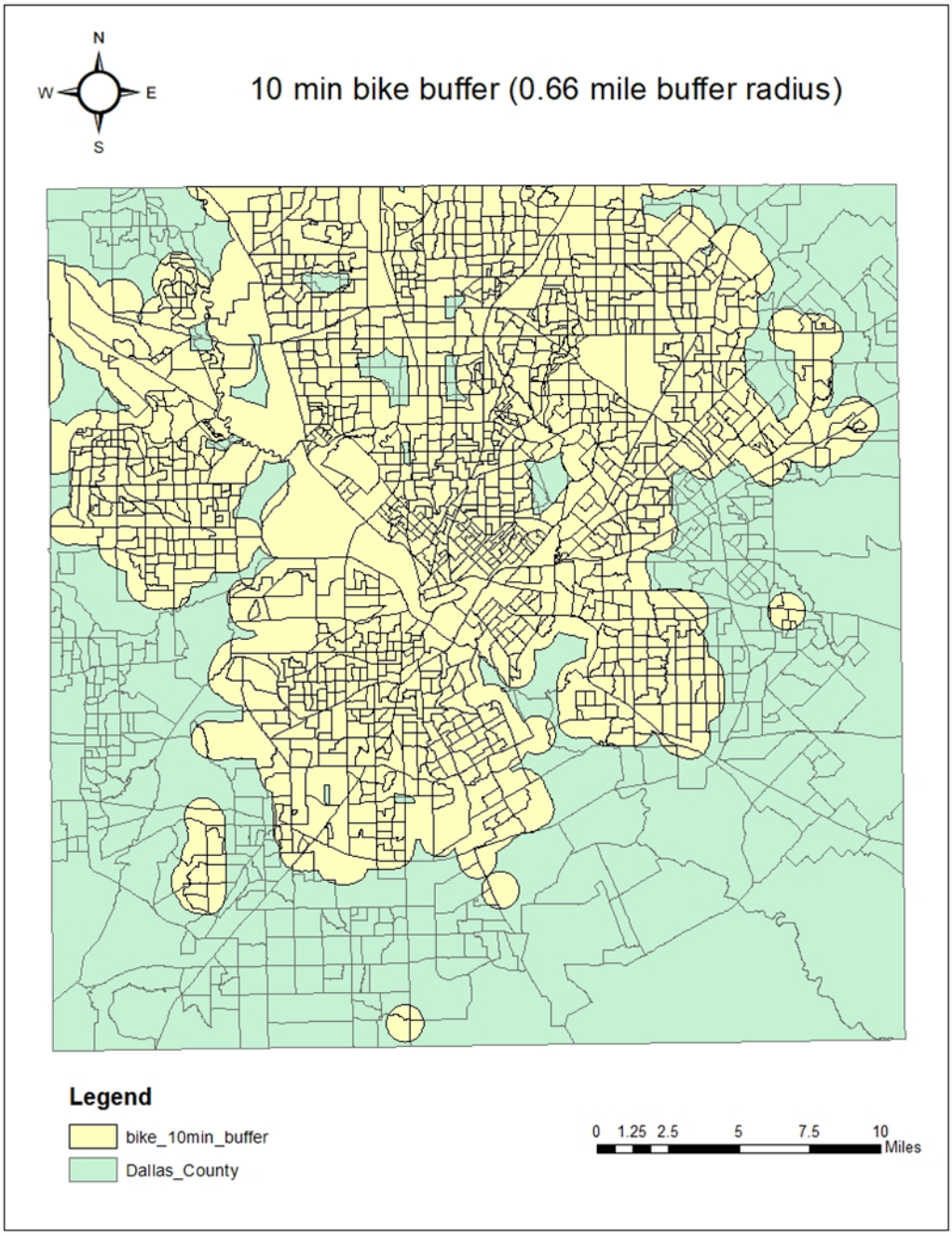

Figure 9.4: 10 min FLM bike travel time for 0.66-mile buffer radius

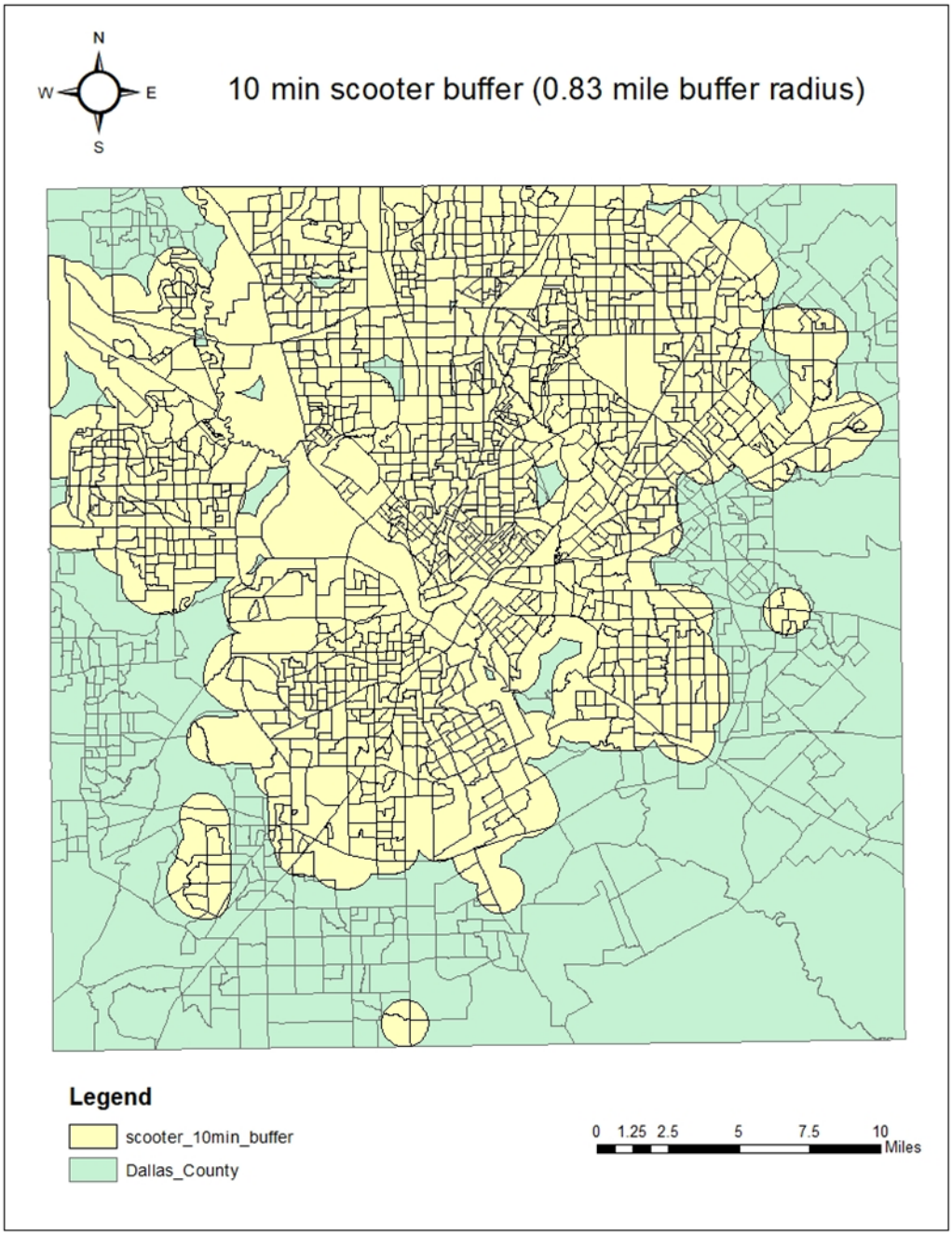

Figure 9.5: 10 min FLM scooter travel time for 0.83-mile buffer radius

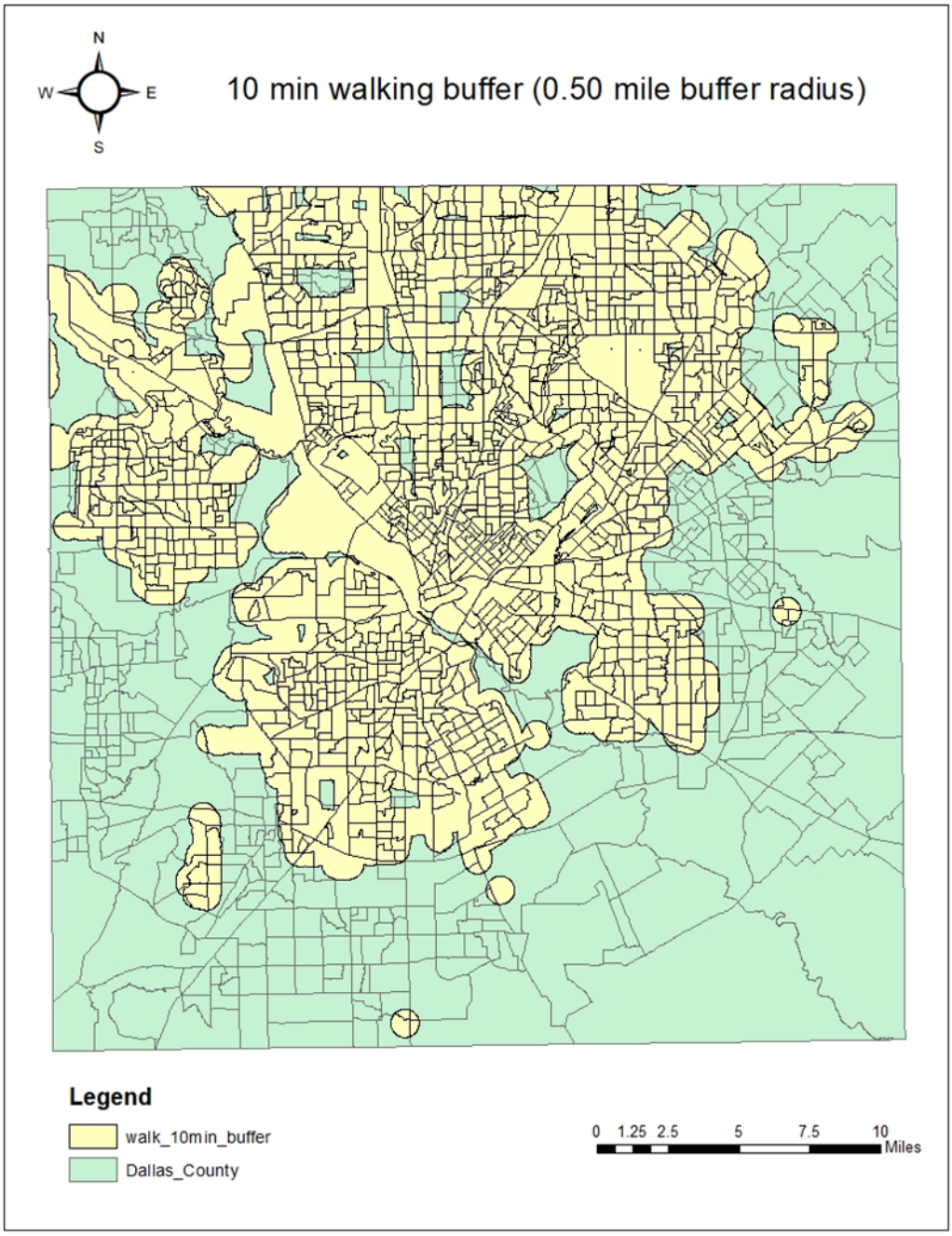

Figure 9.6: 10 min FLM walk travel time for 0.50-mile buffer radius

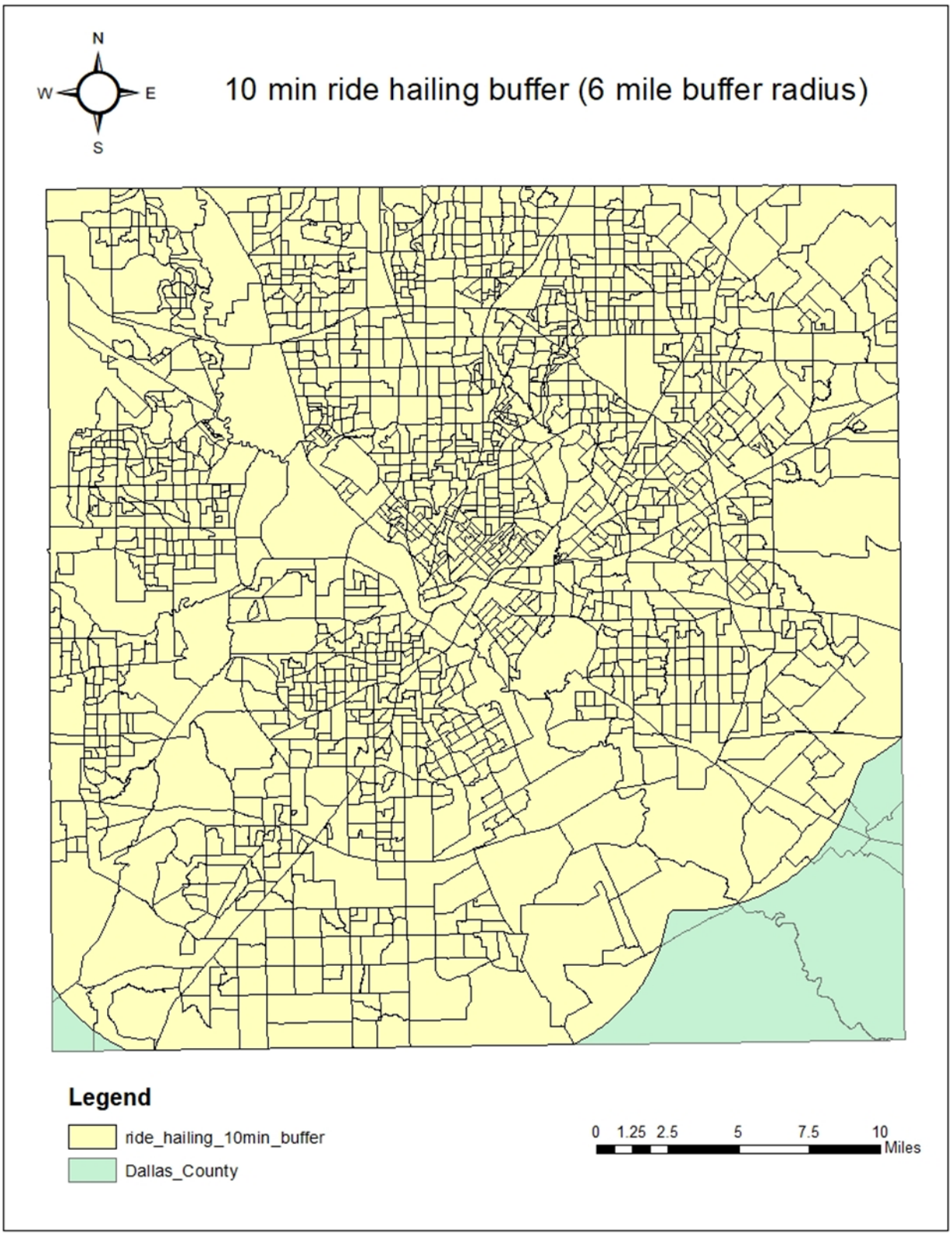

Figure 9.7: 10min FLM ride hailing travel time for 6-mile buffer radius