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UNDERSTANDING PARATRANSIT: EXAMINING TIME INEFFICIENCIES AND THE EFFICACY OF ALTERNATIVE MODES FOR PERSONS WITH DISABILITY

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16. Abstract

The Americans with Disabilities Act (ADA) (1990) mandates that paratransit services should be comparable to fixed-route systems. However, with only 5% of the population utilizing public transit, this comparison does not adequately highlight the disparities between persons with disabilities and those without. This paper examines how the travel times of paratransit trips compare with a counterfactual car trip using trip data from Denver's Regional Transportation District's Access-a-Ride service from January 2019 – June 2021. Through a hotspot and regression analysis, we reveal that paratransit trips experience more inefficient travel times than an equivalent car trip. Demand for paratransit trips is largely located in more suburban cities where housing is relatively affordable but access to destinations via urban infrastructure is relatively low. Paratransit efficiency decreases for specific groups, such as females, older adults, and cash paying riders, and for trips during peak travel times or during inclement weather. During the pandemic, paratransit trip efficiency increased likely because of COVID-19 safety restrictions that reduced other service inefficiencies. This analysis suggests that agencies should focus on improving paratransit services through adopting tools that eliminate pre-travel inefficiencies and leverage the spatial and temporal patterns to optimize operational efficiency.

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Understanding Paratransit: Examining Time Inefficiencies and the Efficacy of Alternative Modes for Persons with Disability

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ABSTRACT

The Americans with Disabilities Act (ADA) (1990) mandates that paratransit services should be comparable to fixed-route systems. However, with only 5% of the population utilizing public transit, this comparison does not adequately highlight the disparities between persons with disabilities and those without. This paper examines how the travel times of paratransit trips compare with a counterfactual car trip using trip data from Denver's Regional Transportation District's Access-a-Ride service from January 2019 – June 2021. Through a hotspot and regression analysis, we reveal that paratransit trips experience more inefficient travel times than an equivalent car trip. Demand for paratransit trips is largely located in more suburban cities where housing is relatively affordable but access to destinations via urban infrastructure is relatively low. Paratransit efficiency decreases for specific groups, such as females, older adults, and cash paying riders, and for trips during peak travel times or during inclement weather. During the pandemic, paratransit trip efficiency increased likely because of COVID-19 safety restrictions that reduced other service inefficiencies. This analysis suggests that agencies should focus on improving paratransit services through adopting tools that eliminate pre-travel inefficiencies and leverage the spatial and temporal patterns to optimize operational efficiency.

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1. INTRODUCTION

1.1 The Importance of Paratransit Services

Paratransit services provide mobility to persons with disabilities who may be unable to access fixed-route transit services or use other travel modes such as driving, walking, or bicycling. These services, or alternative travel options for persons with disabilities, will grow in importance as the percentage of people experiencing (or aging into) disability continues to increase each year. In 2019, there were 43.3 million people (13.2% of the total population) living with disabilities in the United States (The Institute on Disability, 2020). The population of older adults age 65 and older is expected to nearly double in the United States between 2012 and 2050, going from 43.1 million to 83.7 million (Ragland, et al., 2019). These two groups have more diverse mobility needs than the general public. The passage of the Americans with Disabilities Act (ADA) in 1990 aspired to address these diverse needs and create equitable and accessible transportation options for persons with disabilities.

One of the essential goals of the ADA is to remove barriers to accessing fixed-route public transportation for persons with disabilities. The ADA also federally mandates that transit authorities provide complementary paratransit service to populations who are unable to use fixed-route public transportation. Paratransit eligibility is based on federal guidelines set up by the ADA, and the service is only provided to origins and destinations within ¾ miles of fixed-route public transportation, as long as the particular fixed-route is running. The transit agencies are allowed to charge higher fares to paratransit passengers, but the fare cannot exceed twice the amount charged to fixed-route passengers for a comparable trip (The ADA & Accessible Ground Transportation, 2021). The ADA highlights the comparability of paratransit to fixed-route systems within the law's Section 223 as follows:

"(a) General rule

It shall be considered discrimination for purposes of section 12132 of this title and section 794 of title 29 for a public entity which operates a fixed route system (other than a system which provides solely commuter bus service) to fail to provide with respect to the operations of its fixed route system, in accordance with this section, paratransit and other special transportation services to individuals with disabilities, including individuals who use wheelchairs that are sufficient to provide to such individuals a level of service (1) which is comparable to the level of designated public transportation services provided to individuals without disabilities using such system; or (2) in the case of response time, which is comparable, to the extent practicable, to the level of designated public transportation services provided to individuals without disabilities using such system."

Even though the ADA does not define a "comparable" time, from a time efficiency perspective, this means that a paratransit passenger should be able to go from point A to point B within a time comparable to a fixed-route public transit passenger. Although the ADA emphasizes the importance of access to fixed-route transportation systems for persons with disabilities, the complementary paratransit system is a lifeline for many who are unable to use fixed-route transit or drive a car. Scholars find that applying ADA in practice is challenging due to political priorities within organizations, limited guidance and resources, and retrofitting/maintenance issues (Wagner et al., 2024)

1.2 Inefficiencies of Paratransit

Poor on-time performance is one of the most crucial problems experienced by paratransit riders in the United States (National Council on Disability, 2015). A study done by the U.S. Bureau of Transportation Statistics (2003) found that 53% of passengers reported experiencing significant problems with paratransit services, such as the vehicle not showing up during the permissible pickup window or even not showing up at all. Nearly 18% of the passengers stated that unpredictability was a major issue, almost 6% of the passengers reported that service was not available when needed, and 4% said that they could not get through to make a reservation on the telephone. Similar problems surely exist within many transit agency operations in the nation for fixed-route services, but these numbers indicate the perception that paratransit is a door-to-door, somewhat personal, and optimized service is far from the reality. The time inefficiency results in enormous challenges for many paratransit passengers who use these services for time-sensitive trips such as commuting to work or getting to medical appointments (Lezonni & O'Day, 2006; Brooks, 2020). While demand and costs keep increasing for the operators, passenger satisfaction often remains low (Kaufman, 2019) and persons with disabilities report higher travel expenditures compared with persons without disabilities (Oxley & Richards, 1995).

As paratransit demand and costs grew over the years, many transit agencies started raising fares to the maximum, operating at the minimum boundaries allowed, and enforcing restrictive eligibility procedures (Transit Cooperative Research Program, 1998). Nearly all transit systems in the country found paratransit to be costly, with the average one-way paratransit trip costing an average of $29.28 in the 50 largest U.S. transit agencies (Rosenbloom, 2007). Between 1999 and 2012, the annual number of paratransit trips in the United States increased from 68 million to 106 million. While the demand increased, the per-trip cost of paratransit also increased by 138%, compared with an 82% per-trip cost increase in fixed-route bus service over the same period (FTA, 2014). Instead of advancing the operations, agencies adopt paratransit denial rate (total trip denials/total number of requested trips) policies as a matter of costs and benefits (Lewis, et al., 1998). The ADA allows agencies to negotiate requested trips up to one hour before and one hour after the passenger's requested pick-up time and offer an alternative pick-up time. If there are no trips available for the passenger within the negotiation window, then the trip is recorded as "denial." If the passenger is not able to make it and has to turn down the offered alternative, the system records it as a "refusal" (Guidebook for Measuring, Assessing, and Improving Performance of Demand-Response Transportation, 2008). This is just one example of the significant planning and constant negotiation burdens added to the daily travel of persons with disabilities.

1.3 Paratransit within the Car Dominant Space

For persons with disabilities who live in countries like the U.S. or Canada where car culture is dominant, significant social disadvantages occur every day (Wagner et al., 2024). The auto-dominant culture disenfranchises people who cannot afford or drive a car (Hine, 2011). In the U.S., for instance, 84% of workers use cars as their main mode of transportation to work and only 5% use public transportation (U.S. Census Bureau, 2020). Considering these numbers, the ADA rule stating that paratransit needs to be comparable to public transit does not seem fair, given that a significant majority of the nation's population does not utilize public transportation. This constrained comparability is used as a justifier for the unevenness of mobility between persons with disabilities and persons without disabilities, which presents itself between the two groups as uneven travel experiences, uneven access to infrastructure, opportunity, and economy as well as uneven temporalities of mobility (Adey, et al., 2014). Supporters of the emerging post-automobility paradigm, which is characterized by sustainability through cleaner modes of mobility, can perhaps criticize this argument. However, the post-automobility idea has ignored the fact that persons with disabilities have long been excluded from car ownership (Wells & Xenias, 2015). The Bureau of Transportation Statistics ("Travel patterns of American adults with disabilities," 2018) reported that 12.2% of working persons with disabilities and 22.5% of non-working persons with disabilities live in zero-vehicle households compared with 3.9%, respectively, in the case of persons without disabilities. Working-age persons with disabilities are more likely to be poor compared with working-age people without disabilities (Brucker, et al., 2014). This means that those with disabilities are more likely to face financial barriers to owning a personal vehicle. Besides financial barriers, safely operating a car is physically challenging for many of those with disabilities. Few vehicles are produced for persons with mobility disabilities, and technical requirements, which have been designed to regulate driving, also exclude many persons with disabilities from driving (Martin, 2009). As a result, standard vehicles must be modified for the special needs of persons with disabilities. These modifications can vary from simply adding a steering wheel spinner knob to lowering the vehicle's floor or raising the roof to accommodate wheelchairs, which can be extremely costly for persons with disabilities who already have lower rates of employment and disposable income (Darcy & Burke, 2018). For those with disabilities, where owning or driving a car is not an option and fixed-route transit comes with numerous accessibility challenges, comparable paratransit is essential for equal access to opportunity, full participation, independent living, and economic self-sufficiency goals that are laid out in the ADA (1990).

1.4 The Need for Paratransit Research

As older adults become a bigger part of the overall population, and persons with disabilities lead more active lifestyles (Miah et al., 2020), it is essential to investigate the mobility patterns of this population to be able to offer efficient services. Furthermore, studying the efficacy of paratransit is important in enabling data-driven policy and planning decisions (United States Government Accountability Office, 2012) that benefit both agencies and passengers. Even though travel time efficiency is arguably the most important feature for paratransit passenger satisfaction (Denson, 2000), there seems to be a gap in the research on which trip characteristics are associated with paratransit trip times (Cassius et al., 2020; Lu et al., 2017).

In this research, we analyze temporal paratransit patterns and particularly examine the travel time efficiency of paratransit by focusing on the following research question: How does the travel time efficiency of paratransit compare to that of the car? Later in our analysis, we focus on how this comparison varies based on gender as a way to highlight the intersectional relationship between being disabled and female. We utilize a dataset from the Regional Transportation District (RTD), which includes 2.5 years of paratransit origin-destination records across the Denver Metropolitan Region. The analysis relies on attributes from the dataset, which are passenger ID, vehicle ID, actual run ID, gender, age, trip date, start and end time of the trip, pick-up and drop-off location, cost of the trip, and form of the fare paid. This is followed by analysis through appropriate statistical methods in order to examine the relationship between travel time and various variables. We arrive at an in-depth understanding of paratransit passenger travel patterns, especially focusing on the time inefficiency of paratransit as compared with that of automobile transit.

2. LITERATURE REVIEW

To the best of our knowledge, how paratransit's travel time efficiency compares with car travel has not been examined by scholars. Some scholars have investigated the dissimilarities in travel times between fixed-route public transportation and cars as a part of comparing the travel time efficiencies. Liao et al. (2020) compared the travel time by car and transit in four cities (São Paulo, Brazil; Stockholm, Sweden; Sydney, Australia; and Amsterdam, the Netherlands) and found that public transit on average takes 1.2 to 2.6 times longer than driving. Salonen and Toivonen (2013) made the same comparison for the Greater Helsinki Region and applied three different models. All showed that public transit has 1.19 to 3.50 times longer travel durations compared with the private car. Rayle et al. (2016) compared public transit to ride-hailing (Uber, Lyft, Sidecar) in San Francisco and found that the average total travel time was 22 minutes for ride-hailing trips, while the same trips would have averaged 33 minutes by public transit.

The groups who are not able to drive or take fixed-route public transit and depend on paratransit are much more likely to be denied equal opportunity, full participation in society, independent living, and economic self-sufficiency goals that are laid out in the ADA (1990). Wong et al. (2020) found that in New York, transport options are less accessible and slower for disabled workers than they are for non-disabled workers, and that workers with disabilities generally seek higher wages in exchange for commute times. Brucker & Rollins (2019) discovered that workers with disabilities who have similar commute times to workers without disabilities earn substantially less per hour. Additionally, several studies highlight the importance of efficient transportation systems for social participation and community integration of persons with disabilities and older adults (Bezyak et al., 2019; Bascom & Christensen, 2017; Henly & Brucker, 2019; Cochran, 2020).

Some researchers explored the differences between how men and women travel. Compared with men, women tend to have shorter commutes (Haley-Lock et al., 2013). Kwon & Akar (2021) found that, although the gender gap in terms of commute distance has been closing over the years, the amount of change is small. They also concluded that gender gap in terms of commute distance exists if both men and women use automobiles or if one uses an automobile and the other uses public transit. An important factor that contributes to women having shorter commute distances is that they are disproportionately burdened by household duties and often choose jobs closer to home (Crane, 2007; Wheatley, 2013). Shouldering more of the household responsibilities results in women making more non-work trips compared with men (Duncan, 2015; Lee, et al., 2007). Women have to make more non-job-related trips and tend to be better at chaining trips, hence have more complex but efficient trips compared with men (McGuckin & Murakami, 1999; Scheiner & Holz-Ra, 2015; Shirgaokar & Layni-Bennett, 2020).

Some researchers looked at how the COVID-19 pandemic affected travel behavior and the use of paratransit by persons with disabilities. Wang, et al. (2022) concluded that older riders and those with severe mobility challenges tended to stop using paratransit services. However, a substantial percentage of riders with medical needs and riders who lived in areas with low car ownership and low-income rates continued to keep using paratransit services. Ashour et al., (2021) suggested that partnering with transportation network companies would increase the resiliency of the service. Cochran (2020) found that persons with disabilities without car access faced especially limited transportation during the pandemic.

3. STUDY OVERVIEW

3.1 The Regional Transportation District

The Regional Transportation District (RTD) provides public transportation in eight counties in Colorado's Front Range, including Denver, Boulder, Broomfield, and Jefferson counties along with parts of Adams, Arapahoe, Douglas, and Weld counties (Figure 3.1 shows the service area). RTD serves over 3.08 million people within 2,342 square miles (RTD, n.d.). Based on American Community Survey (ACS) 2019 one-year estimates, the total population of those eight counties was around 3.5 million, and 9.5% of the population reported having some sort of disability (Table 3.1 shows further statistics broken down by type of reported disability). Of those who reported a disability, 43% had an ambulatory difficulty. Within the counties served by RTD, 80% of the workers used car, truck, or van as their main mode of transportation to work, while only 4% used public transportation (Table 3.2 breaks down the means of transportation to work for the counties that are served by RTD) (U.S. Census Bureau, 2020). Furthermore, 67% of the persons with disabilities within RTD counties drove alone to work and 5.6% took public transportation. In contrast, 72% of the persons without disabilities drove alone to work and 3.6% took public transportation. Table 3.3 shows the means of transportation to work for the counties served by RTD for the total civilian noninstitutionalized population (U.S. Census Bureau, 2020).

Table 3.1 Disability statistics in the eight counties that are fully or partially within the RTD boundaries

County	Total Populati on	Populati on with disabilit y	% populati on with a	Population With Disability					
				With a hearing difficulty	With a vision difficulty	With a cognitive difficulty	With an ambulatory difficulty	With a self-care difficulty	With an independent living difficulty
Adams	513,712	52,962	10.3%	2.90%	1.7%	3.9%	5.0%	1.5%	4.2%
Arapahoe	648,414	62,638	9.7%	3.00%	1.6%	3.8%	4.6%	1.9%	4.8%
Boulder	324,094	27,573	8.5%	2.70%	1.5%	3.1%	3.4%	1.6%	3.2%
Broomfield	70,115	5,301	7.6%	2.10%	1.6%	2.7%	3.3%	1.3%	2.8%
Denver	720,746	65,123	9.0%	2.50%	1.9%	3.9%	4.3%	1.7%	3.8%
Douglas	349,585	24,573	7.0%	2.30%	0.9%	2.5%	2.8%	0.8%	2.5%
Jefferson	575,685	60,945	10.6%	3.50%	1.9%	3.8%	4.8%	1.7%	4.6%
Weld	321,732	35,395	11.0%	3.80%	2.0%	4.6%	5.1%	1.4%	3.7%
Total	**3,524,083**	**334,510**	**9.49%**	**30.87%**	**17.75%**	**36.56%**	**43.19%**	**15.60%**	**32.28%**

Source: U.S Census Bureau (2019), American Community Survey (ACS) 1-year estimates.

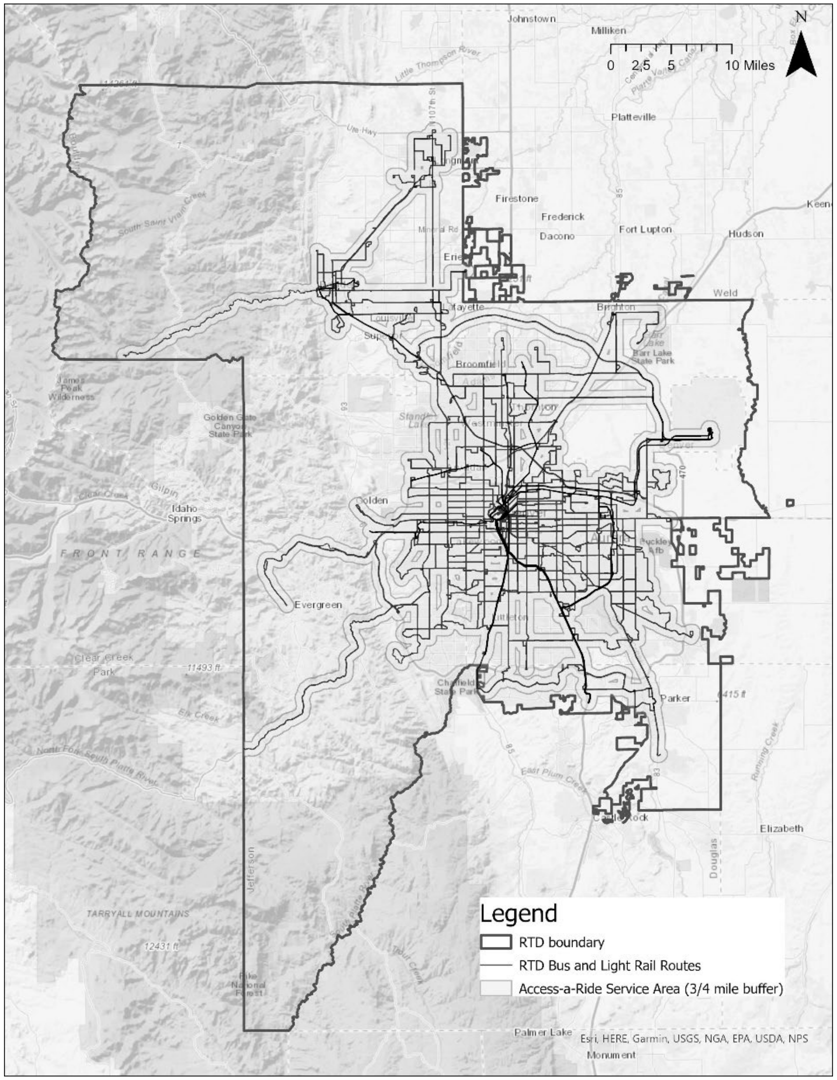

Figure 3.1 RTD's Access-a-Ride service area

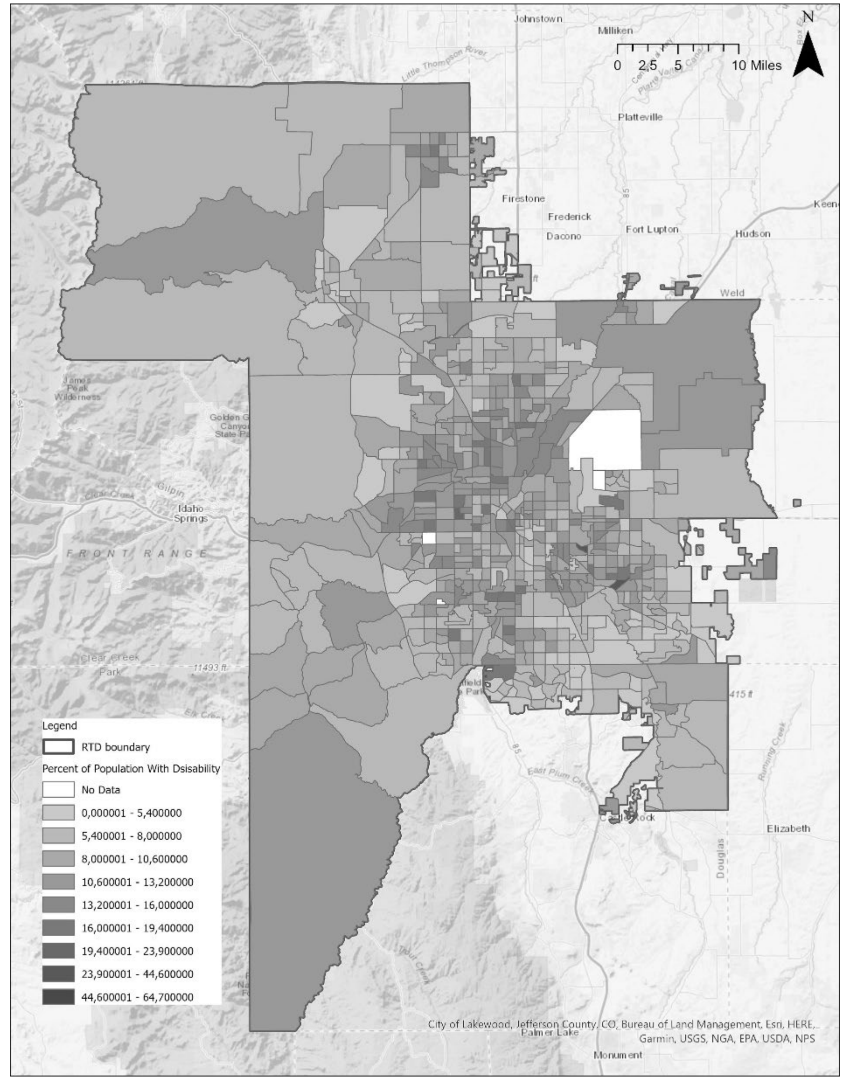

Figure 3.2 Disabled population within RTD boundary (Source: CDC/ATSDR Social Vulnerability Index, 2018)

Table 3.2 Means of transportation to work

	United States		Adams County, Colorado		Arapahoe County, Colorado		Boulder County, Colorado		Broomfield County, Colorado		Denver County, Colorado		Douglas County, Colorado		Jefferson County, Colorado		Weld County, Colorado		RTD total	
Means of transportation to work	Estimate	Percent	Estimate	Percent	Estimate	Percent	Estimate	Percent	Estimate	Percent	Estimate	Percent	Estimate	Percent	Estimate	Percent	Estimate	Percent	**Estimate**	**Percent**
Car, truck, or van	128,732,842	84	228,018	87	287,250	83	119,966	70	30,585	79	294,018	73	146,755	80	256,454	82	136,437	88.78	**1,499,483**	**80**
Public transportation (excluding taxicab)	7,044,886	5	8,924	3	12,489	4	8,193	5	1,385	4	24,704	6	2,995	2	8,929	3	678	0.44	**68,297**	**4**
Bicycle	783,484	1	582	0	1,213	0	6,848	4	251	1	8,262	2	451	0	1,737	1	373	0.24	**19,717**	**1**
Walked	3,954,692	3	3,078	1	5,216	2	7,925	5	429	1	18,849	5	2,384	1	4,638	1	3,111	2.02	**45,630**	**2**
Taxicab, motorcycle, or other means	1,996,655	1	2,338	1	3,995	1	1,555	1	587	2	5,517	1	1,565	1	3,070	1	1,554	1.01	**20,181**	**1**
Worked from home	11,153,095	7	18,865	7	34,447	10	27,740	16	5,523	14	49,588	12	29,268	16	38,253	12	11,523	7.50	**215,207**	**12**
Total	153,665,654	100	261,805	100	344,610	100	172,227	100	38,760	100	400,938	100	183,418	100	313,081	100	153,676	100.00	**1,868,515**	**100**

Source: U.S Census Bureau (2020), American Community Survey (ACS) 5-year estimates.

Table 3.3 Means of transportation to work by disability status for total civilian noninstitutionalized population

	Total civilian noninstitutionalized population (estimate)	Workers age 16 and over	Car, truck, or van – drove alone	Car, truck, or van - carpooled	Public transportation (excluding taxicab)	Walked	Taxicab, motorcycle, bicycle, or other means	Worked from home
United States	*With a Disability*	8,796,957	70.10%	11.30%	4.90%	3.20%	2.80%	7.60%
	No Disability	143,706,223	75.30%	8.70%	4.60%	2.40%	1.70%	7.30%
Adams County	*With a Disability*	16,697	71.00%	11.90%	4.60%	2.10%	1.20%	9.20%
	No Disability	244,678	76.50%	10.90%	3.30%	1.10%	1.10%	7.10%
Arapahoe County	*With a Disability*	18,487	67.40%	9.70%	6.80%	2.90%	3.00%	10.30%
	No Disability	324,210	75.00%	8.60%	3.50%	1.40%	1.40%	10.00%
Boulder County	*With a Disability*	7,026	59.20%	8.00%	5.70%	3.90%	4.80%	18.30%
	No Disability	165,037	62.80%	6.90%	4.70%	4.60%	4.90%	16.00%
Denver County	*With a Disability*	18,702	58.40%	11.20%	10.00%	4.90%	3.70%	11.90%
	No Disability	381,689	66.40%	7.10%	6.00%	4.70%	3.40%	12.40%
Douglas County	*With a Disability*	7,517	73.50%	5.90%	1.40%	1.50%	1.80%	15.80%
	No Disability	175,049	74.20%	5.90%	1.60%	1.30%	1.10%	15.90%
Jefferson County	*With a Disability*	16,104	69.50%	10.30%	4.30%	1.90%	2.70%	11.30%
	No Disability	296,639	75.50%	6.60%	2.80%	1.50%	1.50%	12.30%
Weld County	*With a Disability*	9,293	75.70%	12.00%	1.90%	2.20%	1.90%	6.40%
	No Disability	144,211	78.60%	10.30%	0.40%	2.00%	1.20%	7.60%
RTD*	*With a Disability*	93,826	67.30%	10.29%	5.62%	2.88%	2.70%	11.25%
	No Disability	1,731,513	72.46%	7.96%	3.57%	2.45%	2.10%	11.48%

Source: U.S Census Bureau (2020), American Community Survey (ACS) 5-year estimates. *ACS 2020 did not have any data for Broomfield County in table *S1811*.

3.2 Access-a-Ride

RTD began providing Access-a-Ride services in 1993 to meet the Federal Transit Administration (FTA) provisions for paratransit services. Access-a-Ride is RTD's complementary door-to-door paratransit service that is intended to serve mobility-disadvantaged groups in the Denver Metropolitan Region. Although RTD states that its entire fleet is accessible and ADA compliant, Access-a-Ride had 853,936 annual boardings in 2019 (RTD Facts and Figures, 2021), indicating that paratransit services have a strong customer base. This provision comes with strict eligibility and service guidelines in addition to a high trip planning burden for paratransit customers. Access-a-Ride is only provided within ¾ miles of any non-commuter fixed-route bus or light rail route solely within the RTD boundaries as long as the fixed route at the particular location is running. The eligibility is not based on disability, but rather the functional inability of a person with disabilities to use the fixed-route systems. RTD's Access-a-Ride provides service through 310 RTD-owned dedicated cutaway vehicles that are operated by three contractors: MV Transportation, Via Mobility, and Transdev (Hamilton, 2021). According to the Access-a-Ride customer guide (2020), RTD provides nearly 3,000 daily trips and one-way local and regional trips costing $5 and $9, respectively. A one-way trip to Denver International Airport costs $20. All fares can be paid in cash or with tickets. Customers must schedule the trip between 8 a.m. and 5 p.m. one to five days in advance. Customers are provided with a 30-minute window during which they can expect to be picked up, and the driver does not wait more than six minutes for the customer to show up. At least one hour must elapse between the drop-off and pick-up times. If the customer wants to be picked up again in less than an hour, they need to contact the dispatcher to inquire if it is possible to reschedule a return trip before the one-hour period elapses. These requests are approved on a case-by-case basis and are not always available. RTD has been providing Access-a-Cab service since 2005. It is not meant to replace Access-a-ride and is only offered as a same-day alternative. RTD states that 38% of the regular Access-a-Ride customers also used Access-a-Cab in 2019 (Hamilton, 2021). For this research, we did not have access to the Access-a-Cab data, so we relied on Access-a-Ride information exclusively.

4. DATA AND ANALYTICAL APPROACH

4.1 Data Organization and Assembly

This study looks at Access-a-Ride trip data collected over 30 months, from January 2019 to June 2021. The dataset, obtained from RTD, includes about 1.16 million trips and details important information such as pick-up and drop-off locations, passenger demographics (e.g., gender, birth year), trip costs, fare types, and start and end times for each trip.

To ensure accuracy, we started by removing any entries that were incomplete. We also excluded trips with unrealistic durations—such as end times that were much later than expected or identical start and end times. Additionally, trips involving children under six, who ride for free, were removed since payment details were essential for our analysis. We then calculated the duration of each trip and eliminated those lasting longer than 200 minutes or shorter than five minutes, which we identified as outliers. Each trip was categorized into one of 10 time ranges defined by the Denver Regional Council of Governments (DRCOG) for transportation modeling. To make our analysis more efficient, we randomly selected a 10% sample of the cleaned dataset.

We also estimated car trip durations for the same pick-up and drop-off points using the Google Distance Matrix API, focusing on mid-hour times for each DRCOG range on April 1, 2022. Weather data for each trip date were obtained from Denver International Airport using National Oceanic and Atmospheric Administration (NOAA) datasets.

Table 4.1 contains the outcome variables and the explanatory variables that are associated with the trip time efficiencies. Paratransit trip time includes multiple inefficiencies such as picking up and dropping off other riders, doing paperwork before each ride, traffic congestion, and road closures. The comparable counterfactual automobile trip time includes the factors, mainly congestion and road closures, which affect a planned trip when one maps a route on Google Maps. A summary of the outcome and explanatory variables is shown in Table 4.2.

Table 4.1 Outcome and explanatory variables

	Variable Name	Variable Definition	Variable Calculation
Outcome Variables	Paratransit trip time (min.)	Total trip time between origin and destination by paratransit	Based on trip start-end date (Y-M-D) and time (H:M:S)
	Comparable automobile trip time (min.) (counterfactual)	Total trip time between origin and destination by car	Calculated with Google Distance Matrix API using the *gmapsdistance* R package
Explanatory Variables	Age	Age in years	2022 subtracted by the birth year of the rider
	Total daily precipitation	Millimeters	Cased on the weather station at DIA for the date of the trip
	Average daily temperature	Celsius	Cased on the weather station at DIA for the date of the trip
	Gender	Male or female	Coded one for female and zero for male
	Trip start time	10 skims encompassing different morning peak, evening peak, and off-peak hours	Based on DRCOG's traffic analysis skims
	Pandemic	Before or during the Covid-19 pandemic	Coded one for trips during or after March 2020 (zero otherwise)
	Form of payment	Cash, ticket, or no fare	Categorical variable for form of payment
	Cost	Less than \$5, equals \$5, and more than \$5	Categories coded based on the payment amount.

Table 4.2 Summary of variables used in the analysis

	Obs.	Mean/ Prop.	Std. Dev.	Min	Max
Outcome variables					
Paratransit trip time (min.)	94,994	35.34	21.64	5.02	189.37
Comparable automobile trip time (min.) (Counterfactual)	94,994	17.59	8.61	1.95	74.85
Explanatory Variables					
Age (years)	94,994	54.31	18.33	9.00	105.00
Total daily precipitation (mm)	94,994	0.88	3.10	0.00	57.90
Average daily temperature (°C)	94,994	9.89	10.33	-20.30	29.60
Female (ref. male)	50,285	53%			
Trip during the pandemic (March 2020 and after) (ref. trip before March 2020)	33,841	36%			
Start time (ref. OP1: 11:00 PM – 6:00 AM)					
AM1: 6:00 – 7:00 AM	2,614	3%			
AM2: 7:00 – 8:00 AM	9,828	10%			
AM3: 8:00 – 9:00 AM	12,951	14%			
OP1: 11:00 PM – 6:00 AM	3,098	3%			
OP2: 9:00 AM – 11:00 AM	13,748	14%			
OP3: 11:00 AM – 3:00 PM	30,135	32%			
OP4: 7:00 PM – 11:00 PM	3,124	3%			
PM1: 3:00 – 5:00 PM	15,629	16%			
PM2: 5:00 – 6:00 PM	2,513	3%			
PM3: 6:00 – 7:00 PM	1,354	1%			
Form of payment (ref. ticket)					
Cash	13,483	14%			
Ticket	71,641	75%			
No fare paid	9,870	10%			
Cost (ref. <$5)					
<$5	11,136	12%			
$5	82,477	87%			
>$5	1,381	1%			

Notes: 1) Reference categories are shown as specified in the models (see Table 5.1 in the analysis section)

4.2 Mapping the Demand

We began by mapping the hot spots for paratransit trip pick-up and drop-off locations to better understand the geographical demand before and after the pandemic. Using ArcGIS Pro's Hot Spot Analysis tool, we calculated the Getis-Ord Gi statistic. This local statistic, defined by Getis and Ord (2010), shows how the activity in a specific area compares to the average in surrounding areas. In our analysis, hot spots refer to traffic analysis zones (TAZ) with a high number of trips start locations, surrounded by other TAZs with similar high trip starts. Thus, a TAZ with many trip starts is not automatically considered a hot spot. Cold spots, in contrast, are TAZs with clustering of low trip start locations. (For the Getis-Ord Gi statistic formula, see Appendix A.)

Figures 4.1 through 4.4 illustrate that the hot spots for paratransit demand form a "doughnut" shape, primarily covering suburban areas like Aurora, Lakewood, Westminster, Federal Heights, and south Denver. These regions generally offer more affordable housing compared with Denver but lack adequate transportation options, walkable environments, and access to job centers and essential services. Cold spots appear in Boulder, where strict housing regulations limit the availability and affordability of multifamily homes. This spatial distribution suggests that individuals with disabilities may be prioritizing affordability over accessibility.

Before the pandemic, the hot and cold spots for pick-up and drop-off locations were quite similar, as shown in Figures 4.1 and 4.2. However, Figures 4.3 and 4.4 indicate that during the pandemic, new hot spots emerged in areas like the core and the west and south of downtown Denver, shifting the doughnut sub-regionally. We speculate that individuals with disabilities living in these high-demand areas had to make essential trips, such as for medical appointments. Before COVID-19, this group had stable travel patterns supported by family and social services. The isolation during the pandemic likely led to increased reliance on Access-a-Ride, which explains the rise in pick-up locations in the core and around the doughnut. Notably, drop-off locations (Figures 4.2 and 4.4) remained largely consistent before and during the pandemic.

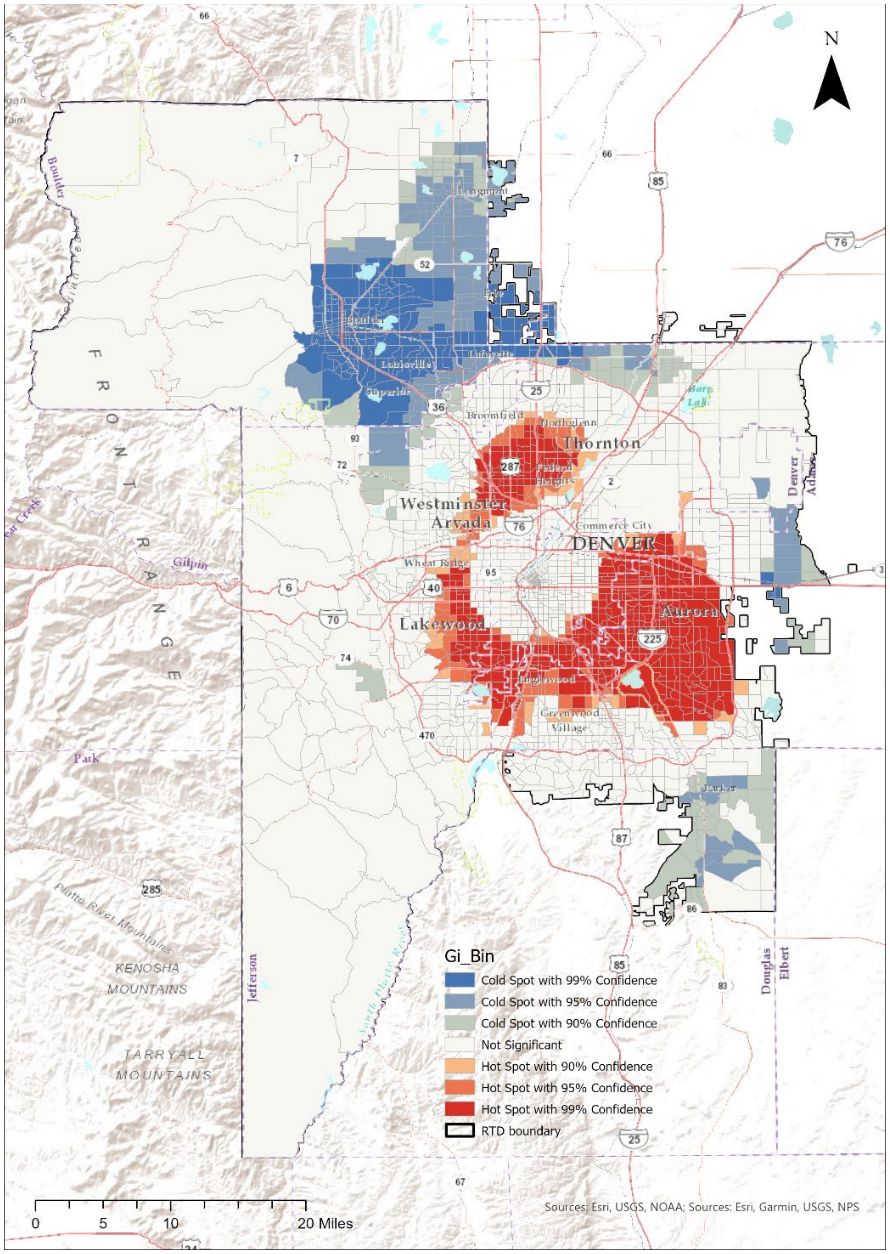

Figure 4.1 Before Covid-19 pandemic pick up hot and cold spots

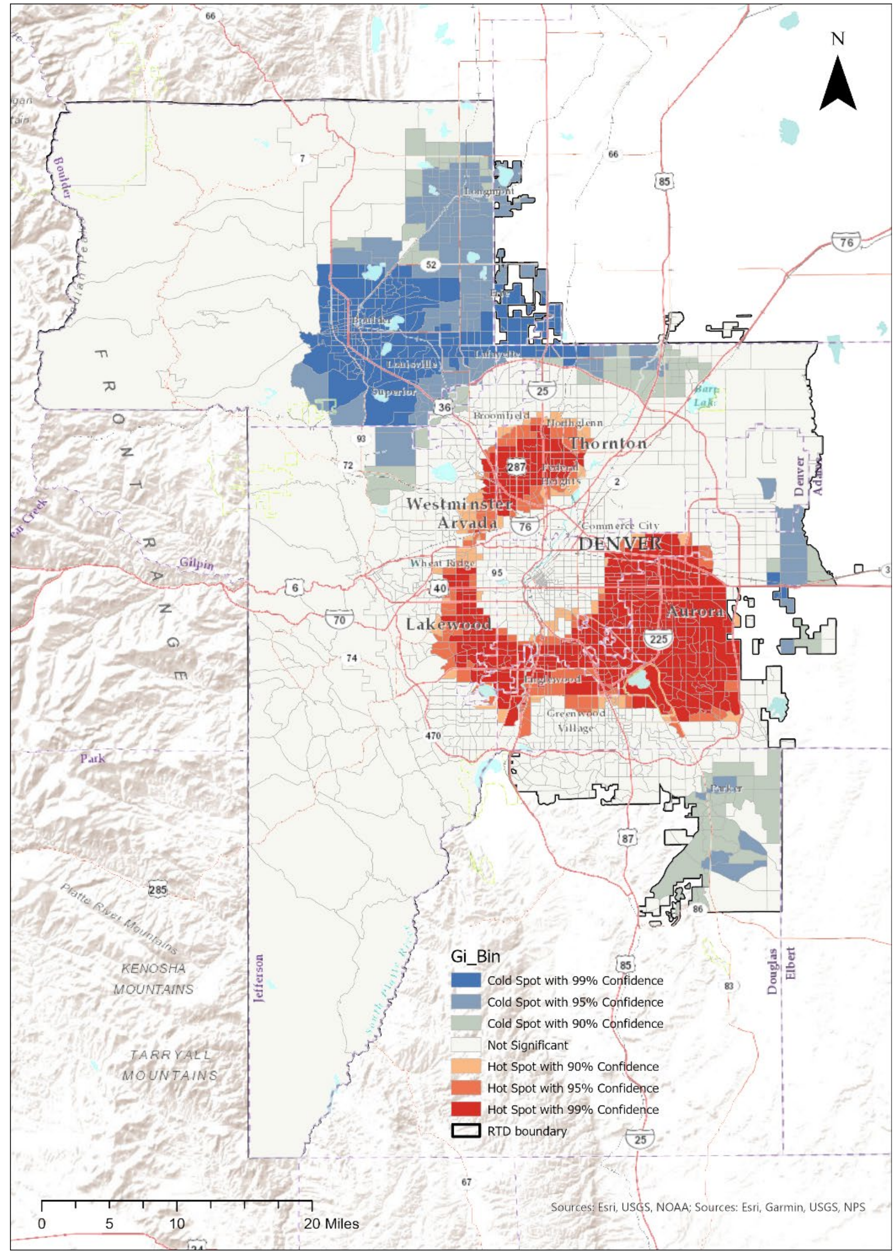

Figure 4.2 Before Covid-19 pandemic drop off hot and cold spots

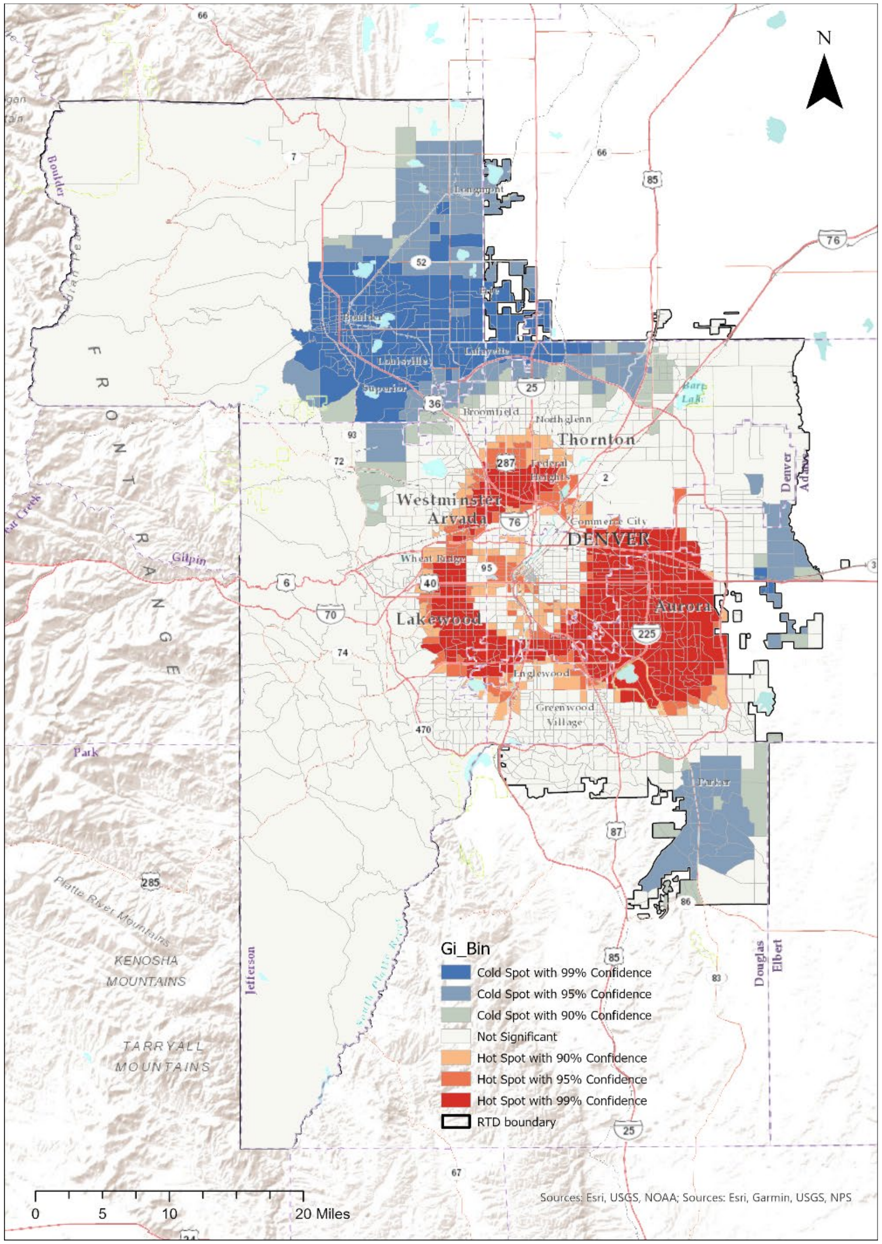

Figure 4.3 During Covid-19 pandemic pick up hot and cold spots

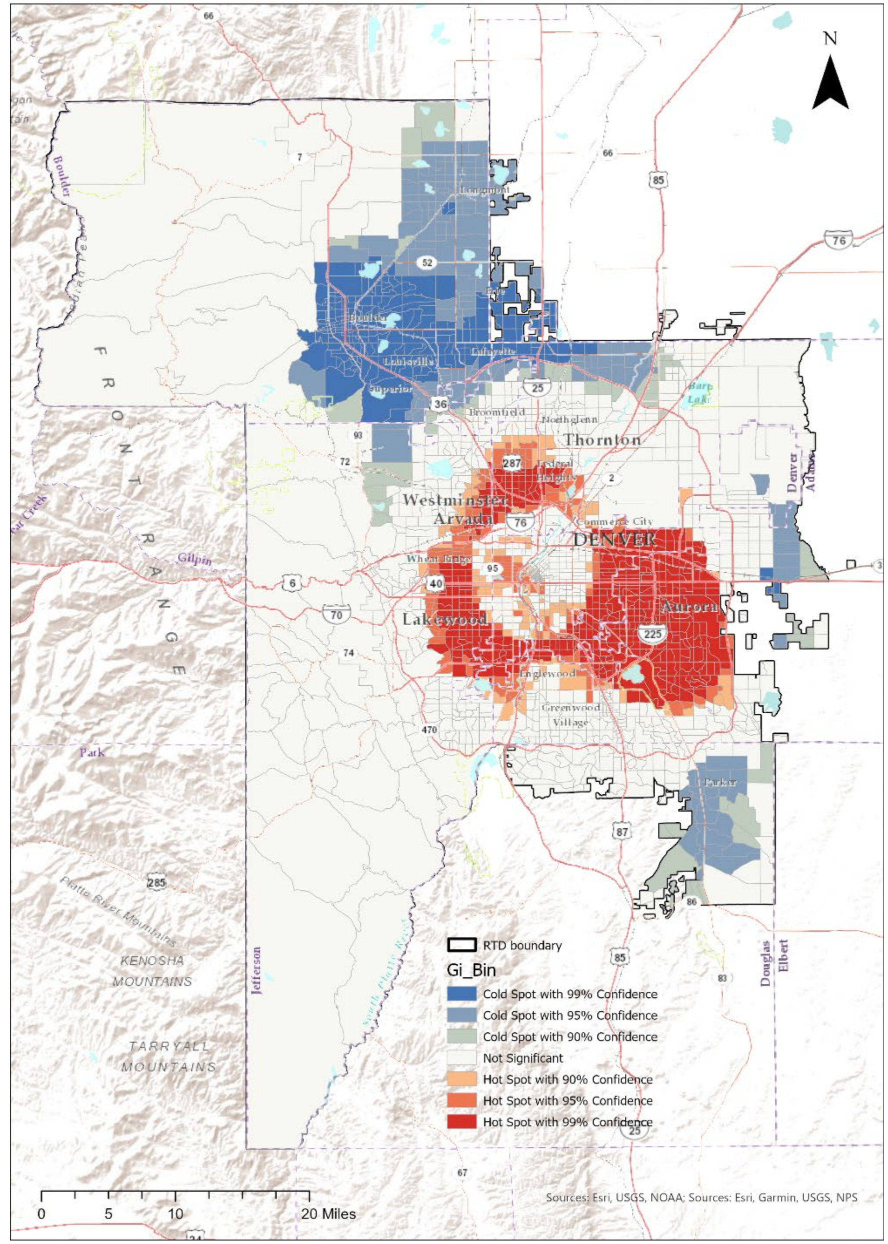

Figure 4.4 During Covid-19 pandemic drop off hot and cold spots

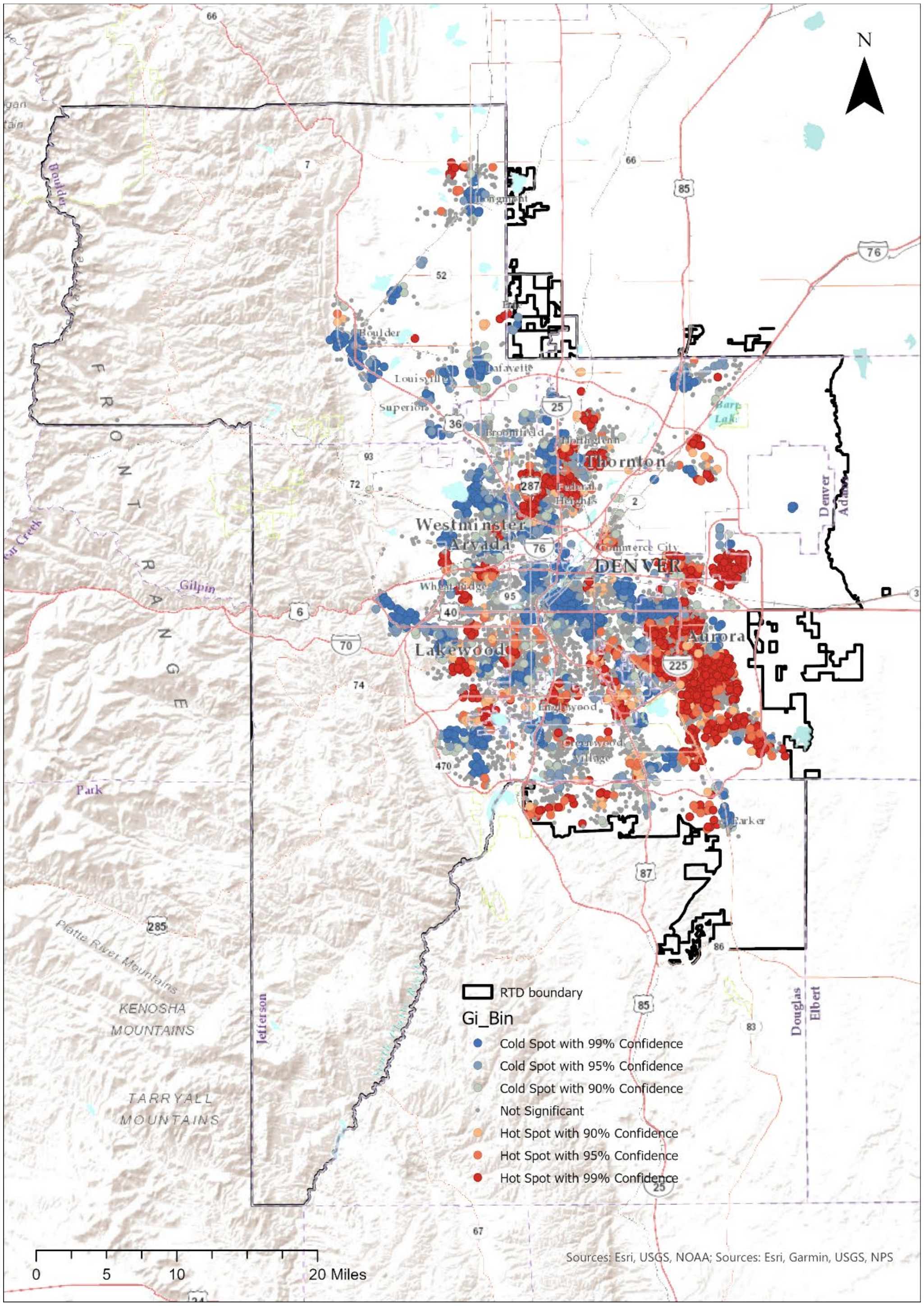

Figure 4.5 Ratio (trip time on paratransit/trip time on counterfactual car mode) hot and cold spots for pick up locations

Figure 4.5 shows the hot spots where high values of the ratio of trip time on paratransit and trip time on counterfactual car mode are clustered. The hot spots here represent the areas where paratransit is significantly less time efficient compared with automotive transit. This pattern again follows a similar pattern to a doughnut.

4.3 Analysis

We utilized ordinary least squared (OLS) regression for the analysis (James et al., 2017; Shirgaokar & Rumbach, 2018). To achieve stable models, we started by running various OLS regressions with the different combinations of explanatory variables and checked for the variables that were consistently statistically insignificant ($p<0.1$). We also looked for variables that had constant negative or positive coefficients and, based on theory and intuition, confirmed that they were appropriate for inclusion in the models. This was accompanied by the generalized variance inflation factor (GVIF) tests. GVIF (formulated as GVIF = VIF[1/(2*df)]) is the variance inflation factor (VIF) corrected by the number of degrees of freedom (df) of the predictor variable (CBU statistics Wiki. (n.d.). VIF examines collinearity (variables that are too closely related to each other) and supplies a score for each variable in the regression (James et al., 2017). As an example, this analysis resulted in the removal of maximum and minimum daily temperatures in Celsius from the equation because GVIF was greater than 5, replacing it instead with the average daily temperature in Celsius.

We also checked residual plots to make sure that the points were randomly dispersed. This resulted in converting the cost variable to a categorical one, which was previously included in the model as a continuous variable.

5. FINDINGS

5.1 Results

Table 5.1 presents the results from two models that examine paratransit trip times and comparable car trip times. The data reveal that women tend to travel shorter distances per trip, which impacts their travel time (Haley-Lock et al., 2013; Kwon & Akar, 2021). On average, female paratransit riders spend less time on the road compared with male riders. However, if the same trip were taken by car, the time difference between gender groups would be much smaller.

During the pandemic, paratransit riders spent an average of nine minutes less traveling. This finding contrasts with research by Wang et al. (2022) in King County, WA, where they found that while there were fewer trips, the pandemic did not significantly affect the average trip distance when controlling for other factors. For Access-a-Ride, if the trips had been made by car, the same group would have traveled 0.44 minutes less than before the pandemic.

Paratransit riders experienced the longest trip times during peak hours, specifically from 7 a.m. to 8 a.m. and from 3 p.m. to 5 p.m., with trips taking about 22 and 12.5 minutes longer, respectively. In contrast, car travel during these times would have resulted in a much smaller time difference of around three minutes.

Although payment methods did not show significant differences in inefficiencies between paratransit and car trips, cash payers tended to have slightly less efficient trips compared with those who used tickets. Notably, riders who did not pay out of pocket (likely covered by programs like Medicare or Medicaid) experienced more efficient trips.

When comparing riders who pay less than $5 to those who pay $5 for a one-way local trip, those paying $5 had significantly more efficient paratransit trips, even though a car trip would have been somewhat less efficient. Interestingly, riders paying more than $5 for regional or airport trips would have experienced less efficient trips if they had traveled by car.

As riders age, trip efficiency decreases, but this decline is slower compared with car trips, which tend to be slightly more efficient. Additionally, increased daily precipitation leads to lower efficiencies for both modes of travel, with car trips being marginally more efficient. In contrast, higher average daily temperatures reduce the time spent on paratransit but do not affect car travel efficiency.

5.2 Discussion

This study demonstrates that paratransit travel is not uniform. It is crucial for paratransit providers to understand the differences in travel patterns and find ways to improve travel time efficiency so they can offer equitable mobility options to all community members. Agencies should also analyze geographic demand to optimize their operations effectively.

There are significant differences in how men and women with disabilities use paratransit. Understanding the intersection of gender and disability is important. Enhancing the time efficiency of paratransit is likely to benefit women with disabilities more than men. This research indicates that people with disabilities were taking more efficient trips during the pandemic, possibly due to picking up fewer passengers, which reduced paperwork, encountering less congestion from fewer cars on the road, or making shorter essential trips like medical appointments or grocery runs. If the same trips were made by car, the time saved would be 0.44 minutes per trip on average, which is minimal compared with the nine minutes saved on paratransit during the pandemic. This highlights the many inefficiencies associated with paratransit compared with car travel.

The time of day significantly affects paratransit trip durations. Travel takes longer during morning and evening peak hours, regardless of the mode. For example, a trip may take 18 minutes less by car between 7 a.m. and 8 a.m. and 10 minutes less from 3 p.m. to 5 p.m. compared with paratransit, highlighting a clear issue with time efficiency. Passengers who paid for their trips with tickets—likely more experienced riders—tended to have more efficient trips than those whose costs were covered by social programs. Conversely, cash payers had the least efficient trips. This suggests that programs aimed at reducing or eliminating pre-travel costs and paperwork can enhance efficiency.

Local paratransit riders would benefit more from car rides compared with regional travelers, who experience less efficient trips in cars. This indicates that improving local operations would be particularly advantageous for those making frequent local trips for work or medical appointments. Finally, older paratransit riders face less efficient trips, suggesting that operational improvements could greatly assist this demographic, especially as the region ages and mobility challenges increase.

As we move forward in the "managed pandemic" period, transit agencies need to recognize that the previous situation was not fair to paratransit riders. Since many individuals with disabilities rely on regular medical trips, service providers must enhance their operations to offer safe, affordable, and efficient transportation.

Table 5.1 OLS model results

	Paratransit trip time							**Comparable automobile trip time (Counterfactual)**						
	Std. Coef.	**Coef.**	**Std. Err.**	**t-value**	**P>|t|**	**Lower limit**	**Upper Limit**	**Std. Coef.**	**Coef.**	**Std. Err.**	**t-value**	**P>|t|**	**Lower limit**	**Upper Limit**
Female (ref. male)	**-0.03**	**-1.51**	0.13	-11.44	0.00	-1.77	-1.25	**-0.05**	**-0.87**	0.05	-16.53	0.00	-0.98	-0.77
Trip during the pandemic (March 2020 and after) (ref. trip before March 2020)	**-0.20**	**-8.83**	0.14	-63.19	0.00	-9.11	-8.56	**-0.02**	**-0.44**	0.06	-7.89	0.00	-0.55	-0.33
Travel start time (ref. OP1: 11:00 PM – 6:00 AM)														
AM1: 6:00 – 7:00 AM	**0.09**	**11.29**	0.54	20.97	0.00	10.23	12.34	**0.04**	**2.23**	0.22	10.33	0.00	1.80	2.65
AM2: 7:00 – 8:00 AM	**0.31**	**21.96**	0.42	52.12	0.00	21.14	22.79	**0.11**	**3.19**	0.17	18.91	0.00	2.86	3.52
AM3: 8:00 – 9:00 AM	**0.14**	**8.93**	0.41	21.86	0.00	8.13	9.73	0.00	-0.08	0.16	-0.51	0.61	-0.40	0.24
OP2: 9:00 AM – 11:00 AM	**0.03**	**1.68**	0.40	4.18	0.00	0.89	2.47	**-0.06**	**-1.57**	0.16	-9.74	0.00	-1.89	-1.26
OP3: 11:00 AM – 3:00 PM	**0.19**	**8.61**	0.38	22.45	0.00	7.86	9.36	**0.23**	**4.32**	0.15	28.15	0.00	4.02	4.62
OP4: 7:00 PM – 11:00 PM	**0.03**	**3.70**	0.51	7.19	0.00	2.69	4.71	**0.15**	**7.13**	0.21	34.64	0.00	6.73	7.54
PM1: 3:00 – 5:00 PM	**0.21**	**12.44**	0.40	31.09	0.00	11.65	13.22	**0.12**	**2.89**	0.16	18.07	0.00	2.58	3.21
PM2: 5:00 – 6:00 PM	**0.06**	**7.96**	0.54	14.62	0.00	6.89	9.02	**0.07**	**3.74**	0.22	17.17	0.00	3.32	4.17
PM3: 6:00 – 7:00 PM	**0.02**	**4.24**	0.66	6.42	0.00	2.95	5.53	**0.05**	**3.62**	0.26	13.68	0.00	3.10	4.13
Form of payment (ref. ticket)														
Cash	**0.01**	**0.49**	0.20	2.47	0.01	0.10	0.88	**0.04**	**0.87**	0.08	10.93	0.00	0.71	1.02
No fare paid	**-0.04**	**-2.95**	0.48	-6.12	0.00	-3.89	-2.00	**-0.08**	**-2.37**	0.19	-12.32	0.00	-2.75	-2.00
Cost (ref. <$5)														
$5	**-0.08**	**-5.18**	0.45	-11.40	0.00	-6.08	-4.29	**-0.12**	**-3.10**	0.18	-17.01	0.00	-3.45	-2.74
>$5	**0.03**	**6.15**	0.71	8.71	0.00	4.77	7.54	**0.10**	**7.18**	0.28	25.38	0.00	6.62	7.73
Age (years)	**0.16**	**0.19**	0.02	8.90	0.00	0.15	0.23	**0.12**	**0.06**	0.01	6.80	0.00	0.04	0.07
Age squared	**-0.22**	**0.00**	0.00	-12.05	0.00	0.00	0.00	**-0.23**	**0.00**	0.00	-12.97	0.00	0.00	0.00
Total daily precipitation (mm)	**0.01**	**0.08**	0.02	3.80	0.00	0.04	0.12	**0.01**	**0.02**	0.01	1.99	0.05	0.00	0.03
Average daily temperature (°C)	**-0.01**	**-0.03**	0.01	-4.39	0.00	-0.04	-0.02	0.00	0.00	0.00	-0.99	0.32	-0.01	0.00
(Intercept)	.	32.31	0.82	39.26	0.00	30.70	33.93	.	18.68	0.33	56.71	0.00	18.04	19.33
Model diagnostics														
Number of obs.	94,994							94,994						
F-test (19, 94974)	729.16							662.29						
Prob > F	0.000							0.000						
Adjusted R-squared	0.13							0.12						
Root MSE	20.22							8.09						
AIC	840,823							666,880						
BIC	841,013							667,069						

Notes: All bolded standardized coefficients and estimates are significant at $p<0.05$

5.3 Conclusion

We aimed to answer the question: How time-efficient is a paratransit trip compared to the same trip by car? Our findings indicate that geographical demand for paratransit is mainly located in suburban areas where housing is affordable but access to transportation, walkable environments, job centers, and essential services is limited. Since people with disabilities are more likely to be living in poverty compared with those without disabilities (Brucker & Rollins, 2019), they often must choose affordability over accessibility. Men and older individuals with disabilities tend to be worse off compared with women and younger riders, respectively.

The pandemic significantly impacted the travel time of people with disabilities compared with those who could drive. We found that during the pandemic, individuals with disabilities were making more efficient trips due to reduced inefficiencies, such as picking up fewer passengers, resulting in less paperwork, encountering less traffic, and making only short, essential trips like grocery shopping. We also discovered that the payment method and fare amount affect time efficiency. Ticket payers had more efficient trips compared with cash payers, while those whose trips were covered by social programs had the most efficient journeys. Weather conditions also played a role; increased precipitation decreased time efficiency for both travel modes, though car trips remained slightly more efficient. Higher daily temperatures led to shorter paratransit trip times, but they did not affect car travel times.

Paratransit providers need to understand actual geographical demand to create effective zoning strategies (Lu et al., 2017). Rather than focusing solely on cost reduction, they should prioritize improving service quality and time efficiency where demand is highest. Transit agencies may need to increase the frequency and number of vehicles in service and explore alternative mobility options to traditional paratransit. Collaborating with ride-sharing services like Uber, Lyft, and taxi companies could help address some inefficiencies, such as reducing paperwork, providing more direct routes, and easing trip planning for people with disabilities. RTD already offers a service called Access-a-Cab and partners with Uber in four zip codes (80013, 80014, 80015, and 80016) during peak hours as part of a pilot program (RTD, n.d.). However, it is essential to ensure that people without internet access or smartphones can also book trips, that vehicles meet the special needs of riders, and that drivers are trained to assist those riders.

There are some limitations to this study. For instance, we could not calculate historical driving times using the Google Distance Matrix API. Although Google provides predictions based on past data, we believe actual trip times during the pandemic would have differed if we could calculate them accurately. Future research should incorporate built environment and sociodemographic factors, as these elements could provide a more detailed understanding and enhance the reliability of the results.

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APPENDIX A. GETIS-ORD *GI* STATISTIC FORMULA

Getis-Ord *Gi* statistic is given on ArcGIS Pro as the following formula (How Hot Spot Analysis (Getis-Ord Gi*) works-ArcGIS Pro, n.d.):

$$Gi* = \frac{\sum_{j=1}^{n} w_{i,j} X_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n \sum_{j=1}^{n} W_{i,j}^2 - \left(\sum_{j=1}^{n} W_{i,j}\right)^2\right]}{n-1}}}$$

(1)

where x_j is the attribute value for feature *j*, $w_{i,j}$ is the spatial weight between feature *i* and *j*, n is equal to the number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} X_j}{n}$$

(2)

$$S = \sqrt{\frac{\sum_{j=1}^{n} X_j^2}{n} - (\bar{X})^2}$$

(3)

where $\bar{X}$ is the mean of all measurements and *S* is the standard deviation of all measurements.