



Exploring Shared Micromobility as an Alternative Transportation Option: Opportunities and Challenges in U.S. Mid-sized Cities and Small Towns

A Technical Report Submitted to the Rural Equitable and Accessible Transportation (REAT) Center and the United States Department of Transportation

FINAL REPORT

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February 2025

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METRIC CONVERSION CHART

When You Know	Multiply by	To Find
Length		
inches (in)	25.4	millimeters (mm)
feet (ft)	0.305	meters (m)
yards (yd)	0.914	meters (m)
miles (mi)	1.61	kilometers (km)
Volume		
fluid ounces (fl oz)	29.57	milliliters (mL)
gallons (gal)	3.785	liters (L)
cubic feet (ft ³)	0.028	meters cubed (m ³)
cubic yards (yd ³)	0.765	meters cubed (m ³)
Area		
square inches (in ²)	645.1	millimeters squared (mm ²)
square feet (ft ²)	0.093	meters squared (m ²)
square yards (yd ²)	0.836	meters squared (m ²)
acres	0.405	hectares (ha)
square miles (mi ²)	2.59	kilometers squared (km ²)

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Exploring Shared Micromobility as an Alternative Transportation Option: Opportunities and Challenges in U.S. Mid-sized Cities and Small Towns		5. Report Date 02/28/2025	
		6. Performing Organization Code 59-0977035	
7. Author(s) Angela Kitali https://orcid.org/0000-0002-1962-162X Emmanuel Kidando https://orcid.org/0000-0001-6882-5023 Jeffrey P. Walters https://orcid.org/0000-0001-6655-1233 Heather Dillon https://orcid.org/0000-0002-4467-2306 Panick Kalambay https://orcid.org/0000-0002-0815-3074 Abdul S. Ngereza https://orcid.org/0009-0009-2709-6157		8. Performing Organization Report No.	
9. Performing Organization Name and Address School of Engineering and Technology, University of Washington Tacoma 1900 Commerce Street Tacoma, WA 98402-3100		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. 69A3552348321	
12. Sponsoring Agency Name and Address Rural Equitable and Accessible Transportation Center 2525 Pottsdamer Street Tallahassee, FL 32310		13. Type of Report and Period Covered Final Report Period Covered: 03/01/2024 – 02/28/2025	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract This report examines shared micromobility as an alternative transportation option in mid-sized U.S. cities, small towns, and rural areas, focusing on opportunities, challenges, and equity concerns. It is divided into three chapters: an analysis of micromobility usage patterns, a crash data analysis, and a discussion on the need for equity standards in micromobility services. The first chapter analyzes micromobility usage in Tacoma using Razor micromobility data. It identifies disparities in usage based on race, gender, income, and infrastructure access. High micromobility usage is observed in areas with better bike lanes, pedestrian trails, and transit access, although these areas often have poor pavement conditions. Lower vehicle ownership correlates with higher micromobility use, while middle-income groups are less likely to adopt these services. Recommendations include expanding infrastructure, implementing pricing programs, and addressing safety concerns to encourage ridership. The second chapter examines micromobility crash data in Washington, identifying three crash clusters and their contributing factors. All micromobility crashes occurred in urban settings. Recommendations include infrastructure improvements that separate micromobility users from traffic, as well as educational programs targeting older drivers and younger riders. The third chapter addresses the lack of consistent regulation in the shared micromobility sector. A survey of transportation professionals reveals barriers such as high costs and unclear regulations. Transportation authorities should take a more active role in regulation and expand micromobility services in both urban and rural areas. In conclusion, the report highlights the need for comprehensive strategies to improve equity, safety, and regulatory consistency in shared micromobility services.			
17. Key Words Micromobility, Usage patterns, Access, Equity, Body injury, Transportation professional, Cluster correspondence analysis, Bayesian quantile regression		18. Distribution Statement No restrictions	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 56	22. Price

ACKNOWLEDGEMENTS

This project was sponsored by the Rural Equitable and Accessible Transportation (REAT) Center and U.S. Department of Transportation. The Principal Investigators would like to thank the representatives of the REAT Center for their valuable feedback throughout the project activities.

EXECUTIVE SUMMARY

This report explores shared micromobility as an alternative transportation option in mid-sized U.S. cities, small towns, and rural areas, focusing on its opportunities, challenges, and equity concerns. It is structured into three chapters: an analysis of micromobility usage patterns, crash data analysis, and a discussion on the need for equity standards in micromobility services.

Chapter one investigates micromobility usage in Tacoma, using a BQR model with Razor micromobility data. The analysis highlights disparities in usage based on factors such as race, gender, income, and infrastructure access. Micromobility is more commonly used in areas with good bike lanes, pedestrian trails, and transit access, though these areas often suffer from poor pavement conditions. Lower vehicle ownership correlates with higher micromobility use, while middle-income groups, who tend to rely on cars, are less likely to adopt these services. Environmental factors, such as moderate slopes and tree coverage, also influence ridership. To improve equity, the report recommends expanding infrastructure, implementing pricing programs, and addressing safety concerns to encourage female. Additionally, targeted expansion in high-density, high-demand areas with strong transit connections would optimize service efficiency. The report also advocates for expanding micromobility options in rural areas to improve first- and last-mile connectivity to essential services.

Chapter two examines micromobility crash data in Washington, revealing three distinct crash clusters. The first cluster includes crashes on roadways or sidewalks, often involving female riders over 30, with minor injuries, due to distracted or improperly maneuvering drivers. The second cluster involves older male drivers (65+) failing to yield to micromobility users at signalized intersections, causing orthopedic injuries. The third cluster focuses on younger users (under 30), who disregard traffic rules and speed at crosswalks, contributing to more severe injuries. The report recommends investing in infrastructure that separates micromobility users from vehicle traffic, such as dedicated bike lanes. Educational programs targeting older drivers and younger micromobility users are crucial for improving safety. Improved intersection designs and road maintenance, especially in high-risk areas, would also help reduce crashes.

Chapter three highlights the shared micromobility sector's lack of consistent regulation. A survey of transportation professionals identified significant barriers, including high costs, inadequate infrastructure, and unclear regulations. Many organizations lack a clear definition of equity and strategies for ensuring equitable access to these services, leaving much of the responsibility to private vendors. The report suggests that transportation authorities should take a more active role in regulating micromobility, including investing in alternative transit options and establishing a unified regulatory framework. Further research should focus on how municipalities can better coordinate micromobility services and expand options in rural areas to meet mobility needs.

In conclusion, the report emphasizes the need for a comprehensive approach to shared micromobility that focuses on equity, safety, and consistent regulation. Expanding infrastructure, implementing equity-focused strategies, improving safety, and considering rural areas in service expansion will help create a more inclusive and sustainable transportation system.

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LIST OF ACRONYMS AND ABBREVIATIONS

BQR	Bayesian Quantile Regression
CBG	Census Block Group
CCA	Cluster Correspondence Analysis
CI	Credible Interval
DOT	Department of Transportation
FHWA	Federal Highway Administration
NACTO	National Association of City Transportation Officials
NGO	Non-Governmental Organization
REAT	Rural Equitable and Accessible Transportation Center
RPO	Regional Planning Organization
TMC	Tacoma Municipal Code
USDOT	United States Department of Transportation
WSDOT	Washington State Department of Transportation

1. INTRODUCTION

1.1. Background

Since 2010, micromobility has rapidly emerged as an alternative to private automobiles, with over 207 million trips taken across the U.S. (NACTO, 2018). It aligns with the goals and policies of various U.S. transportation agencies by expanding access to active transportation, addressing barriers to bike and scooter ownership, bridging first/last mile gaps, and enhancing transit connectivity. As a result, many cities and towns nationwide are adopting shared micromobility systems for trips that are too far to walk yet too short to drive.

As defined by the Federal Highway Administration (FHWA), micromobility refers to small, low-speed, human- or electric-powered transportation devices, such as bicycles, scooters, electric-assist bicycles, and electric scooters (e-scooters) (Price et al., 2021). Shared micromobility services generally fall into two categories: docked and dockless systems. Docked systems require users to rent and return devices at designated stations, which often provide payment options and charging infrastructure, reducing the need for overnight collection. In contrast, dockless systems allow users to start and end trips anywhere within a predefined zone, requiring frequent collection for charging and typically necessitating a smartphone application for reservations.

Micromobility, being a relatively new and emerging transportation option, presents challenges for most agencies, as they often lack data-driven tools to assess the costs and benefits of shared micromobility systems. Additionally, there is limited guidance on how to effectively integrate shared micromobility into the planning and design of transportation networks. Much of the existing discussion around micromobility focuses on major cities, with minimal attention given to its effectiveness in mid-sized cities and rural towns. This is largely due to the fact that micromobility systems tend to thrive in areas with high population density, which rural areas typically lack.

1.2. Project Objectives

This project aims to gain insights into the use of micromobility in mid-sized and small cities in Washington State by mapping and classifying shared micromobility trips, analyzing micromobility related crashes, and examining interview data from city and town staff.

Specifically, the following questions are explored:

- Who is using shared micromobility, and for what kinds of trips?
- What factors affect shared micromobility device ridership?
- Is the shared micromobility system serving mid-sized cities and small towns equitably?
- What factors affect the safety of micromobility device users?

1.3. Project Relevance to the REAT Themes and USDOT Strategic Plan

The proposed project fits very well the broad themes of the REAT Center and explicitly contributes to the following thrust areas:

Access and Equity: This project examines emerging micromobility modes in mid-sized cities and small towns. While micromobility is typically discussed through examples from metropolitan cities, there is limited exploration of its effectiveness in mid-sized cities and small towns. The project explores micromobility usage patterns from an equity perspective in these areas. Also, it

challenges the technological optimism of this mode of transportation by revealing opportunities and challenges that impede its expansion. The city of Tacoma was used as a case study.

Safety of Vulnerable Users: The safety of micromobility users, who are also considered vulnerable road users, is a critical issue. Micromobility users are at a heightened risk of injury in traffic crashes compared to occupants of motor vehicles. This project focuses on identifying the factors associated with crashes involving micromobility users in Washington state.

Furthermore, the proposed project is expected to contribute to achieving several key goals outlined in the USDOT 2022-2026 Strategic Plan, including: (i) improving the safety of transportation systems and their users; (ii) promoting equity across transportation systems and the communities they serve; (iii) developing innovative, purpose-driven decision support systems to benefit transportation users both now and in the future; and (iv) establishing new policies and procedures, particularly focused on emergency evacuation planning, to address the critical needs of communities.

1.4. Report Structure

The rest of this report is structured as follows:

- Chapter 2 focuses on micromobility usage patterns in mid-sized cities, with a specific emphasis on the city of Tacoma. It explores the trends and patterns of micromobility usage from an equity standpoint.
- Chapter 3 delves into the influence of factors associated with micromobility crashes. It examines how the various factors contributing to crashes are clustered and related to the type of body injuries sustained by micromobility users.
- Chapter 4 discusses the need for a standard of equity in shared micromobility using interview data collected from transportation professionals, including those from Departments of Transportation (DOTs), Regional Planning Organizations (RPOs), local governments, non-governmental organizations (NGOs), and the private sector.
- Chapter 5 presents the conclusions, summarizing key findings from the analysis and offering recommendations for future research, policy, and practice related to micromobility in mid-sized cities and small towns in rural areas.

2. MICROMOBILITY USAGE PATTERNS IN A MID-SIZED CITY

2.1. Introduction

Micromobility, including electric scooter sharing, has rapidly emerged as a popular and sustainable transportation option. With their compact structure and electric-powered engines, micromobility devices provide an eco-friendly and efficient means of navigating congested streets, particularly during rush hours. It effectively addresses first- and last-mile connectivity issues, enabling door-to-door travel (Karpinski et al., 2022; Yang et al., 2020). Micromobility devices are generally electric-assisted and, therefore, eliminate the need for physical effort. Their built-in electric power systems make them particularly beneficial in hilly terrains or for longer commutes.

The growing role of shared micro-mobility in enhancing urban mobility and improving access to public transit has spurred a surge in research examining its equitable use and overall accessibility. Shared micromobility has been researched from various perspectives, including spatiotemporal usage patterns, accessibility to key destinations, factors influencing adoption and usage, and broader equity implications (Aboueela et al., 2024; Kalambay & Pulugurtha, 2022a). Understanding the relationship between micromobility, equitable access, and built environment characteristics—such as road density, land use patterns, and transit connectivity—is crucial for transportation planners and policymakers. Examining these interactions through quantitative analyses can provide deeper insights into how micromobility systems contribute to bridging transportation gaps, particularly in underserved areas. Such analyses can also help identify barriers to access, optimize infrastructure planning, and guide policy decisions that promote more inclusive, efficient, and sustainable urban mobility solutions. However, not much is known regarding the use of micromobility in mid-sized and small towns in rural areas.

This chapter focuses on examining micromobility usage patterns in Tacoma, a mid-sized city in Washington, to better understand its relationship with equity. By analyzing neighborhood characteristics, this study aims to identify how factors such as income levels, population density, access to public transit, and infrastructure availability influence micromobility adoption and usage. The findings from this analysis can provide valuable insights into how micromobility systems can be more effectively integrated into city or town planning to ensure broader accessibility and equitable transportation opportunities for all residents.

Below, the remaining sections of the chapter are organized as follows. The second section of this chapter focuses on a review of current equity-related research on micromobility, highlighting the methods employed and factors considered to evaluate the accessibility to shared micromobility. The third section presents the data collection, processing, and integration performed prior to the analysis. The methods used for data integration and analysis are also detailed in this section. The fourth section presents the analysis results and discussion of the final findings, followed by a summary of findings and practical recommendations that might help close the existing inequity gaps in micromobility use.

2.2. Literature Review

The inequitable use of micromobility services stems from multiple factors, including structural barriers, affordability, spatial distribution, and built environment characteristics. One major limitation is the concentration of micromobility trips in high-demand urban areas, particularly downtown cores, while suburban and lower-density neighborhoods often lack sufficient coverage

(Brown et al., 2022). Additionally, affordability concerns may prevent lower-income populations from utilizing these services, further exacerbating disparities. Beyond economic and spatial constraints, micromobility systems (shared systems) also impose digital access requirements, excluding individuals without smartphones, digital banking access, or adequate digital literacy (Dill & McNeil, 2021). Prior research has primarily focused on user-specific factors contributing to inequitable access, such as socioeconomic status, demographics, and proximity to available vehicles (Javid & Sadeghvaziri, 2023). Shared micromobility is often perceived as catering predominantly to young, high-income males, as well as tourists and students (Duran-Rodas et al., 2020). However, inequities in micromobility usage are not solely driven by individual characteristics and service distribution. The built environment plays a crucial role, with factors such as land use patterns, neighborhood design, and the accessibility of key destinations significantly influencing mobility opportunities. The presence of points of interest within a reasonable travel distance and cost can determine whether SMS is a viable transportation option for different communities (Xu et al., 2022). Addressing these structural and environmental challenges is essential to ensuring that SMS contributes to equitable urban mobility.

Although the introduction of new transportation modes is generally expected to enhance accessibility by increasing travel options, this is not always the case with shared micromobility services. Structural barriers inherent in the service's design limit access for certain population groups, leading to inequitable usage (Shaheen, 2018). To understand these disparities, various methods have been employed to assess micromobility usage, with most studies focusing on two key dimensions: user characteristics and vehicle availability. For instance, economic indices such as the Lorenz curve were used by Aman et al. (2021) to evaluate bikesharing equity in Austin, TX, while Bai and Jiao (2024) applied an opportunity index to assess e-scooter accessibility in the same city. Other studies have relied on regression models to analyze the influence of socioeconomic and demographic factors on SMS ridership. Javid and Sadeghvaziri (2023) and McQueen and Clifton (2022) applied this approach to bikesharing in New York and e-scooter sharing in Portland, Oregon, respectively.

In this study, we hypothesized that the spatial (Census block group – CBG level) distribution of sociodemographic, economic, and on-and off-road network characteristics affect micromobility usage. On- and off-road network characteristics are infrastructure, transportation access, traffic exposure, environment, terrain, and land use related. We also hypothesize that the effects of these CBG-level characteristics differ according to micromobility usage levels with different population densities. Using a Bayesian quantile regression (BQR) approach, we examined the nonlinear effect of micromobility usage in Tacoma, a mid-sized city in Washington state, USA, where micromobility is not yet as well established as in larger cities. We aim to (1) quantify micromobility usage and describe its spatial distribution and (2) examine the quantile effects of the above-mentioned neighborhood-level characteristics on micromobility usage. Such an approach helps identify the neighborhood-level characteristics that affect low-trip rate neighborhoods differently than high-trip rate neighborhoods, ultimately highlighting opportunities and barriers to the widespread adoption of micromobility in mid-sized and small cities across U.S. states.

2.3. Materials and Methods

2.3.1. Micromobility Trip Data Description and Cleaning Process

Razor launched Tacoma's first-ever micromobility pilot program in May 2021, introducing shared e-scooters and, later, e-bikes. The e-bike component was added in May 2023. Over the program's duration, which ended in September 2023, Razor's devices facilitated more than 233,081 trips, covering a cumulative distance of 338,205 miles (City of Tacoma, 2025). This study utilized data from Razor for the period between May 2021, and August 2023, a time when the program had gained significant traction and reached a mature operational phase.

Micromobility riders are required to use designated spaces such as bike lanes, cycle tracks, sidewalks, or paved trails. Riding on roads with speed limits greater than 25 mph is permitted only if a designated bike facility or sidewalk is available. The city collaborated with Razor to implement GPS-based slow-speed zones to enhance safety in high-pedestrian activity zones and areas with limited bicycle infrastructures, such as downtown Tacoma and Ruston Way. In these zones, an automatic speed governor limited the devices' speed to 8 mph. Riders could view maps of these slow-speed zones through the Razor Share app.

The data contains detailed trip-level information, including bike or scooter IDs, trip IDs, geographic coordinates for the start and end locations, trip start and end times, trip duration, and distance traveled. To ensure data quality and reliability, we applied a rigorous data-cleaning process guided by four filtering criteria: trip duration, distance, speed, and spatial location. Trips starting or ending outside the city boundaries of Tacoma were excluded. The maximum was limited to 120 minutes, aligning with the typical operational capacity of a fully charged scooter or bike battery, which lasts approximately two hours. Razor's devices were designed with a maximum speed of 15 mph (City of Tacoma, 2025). Therefore, the maximum distance traveled with a full battery was capped at 50 kilometers (31.07 mi). To exclude false starts, the minimum distance and duration for a valid trip were set at 100 m (~0.06 mi) and one minute, thresholds supported by previous studies to ensure trips reflect meaningful travel rather than incidental movement or GPS drift (Abouelela et al., 2024; Abouelela et al., 2023). The final dataset included 116,398 trips with 1,380 scooters and bikes, covering a total distance of 266,311 miles. Table 1 shows the summary statistics of individual trips in Tacoma throughout the study period. There is a substantial variability in daily trips, which may indicate differences in trip behavior across different locations or variations in service availability.

Table 1 Summary statistics of individual micromobility trips.

Statistic	Min	Max	Mean	Median	SD
Count of daily trips	2.00	661.00	145.00	115.00	112.00
Trip distance (mi)	0.06	19.30	2.29	1.73	1.94
Trip duration (min)	1.00	120.00	17.80	13.60	14.10
Average speed (mph)	0.15	15.00	8.07	7.96	3.32

Figure 1 presents a heatmap illustrating the distribution of trips across hours and months throughout the study period. The data reveals that the majority of trips (>250) occurred between 6 a.m. and 7 p.m., with the peak period in July, particularly between 2 p.m. and 4 p.m., where over 750 trips were recorded. Additionally, it is evident that the program gained significant traction

during its first year but gradually saw a decline in the number of trips as the program progressed, especially toward the end. Seasonal trends also emerge, with the majority of trips taking place during the Summer and Fall months.

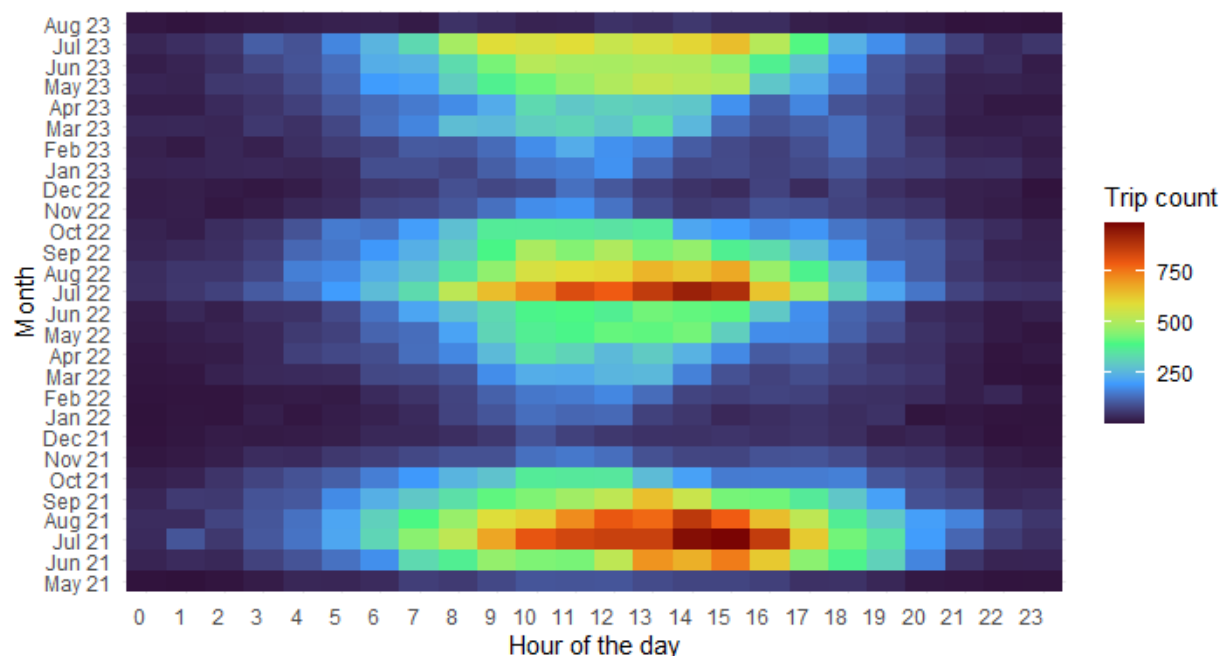


Figure 1 Heatmap of micromobility trips across hours and months.

2.3.2. Data Aggregation

This study uses data aggregated at the CBG level, the unit for most key variables available for analysis. Tacoma is divided into 153 CBGs across eight neighborhood council districts. Trip data was aggregated on a weekly basis and averaged throughout the study period across CBGs. Low daily counts might result in many zero-trip days, especially in less active CBGs. Aggregating to a weekly level reduced the number of zeros and provided more stable patterns for modeling. In addition to micromobility trip data, information on the equity index, bicycle lanes, slopes, pavement conditions, speed limits, and land use was also aggregated at this level. All data was obtained from the City of Tacoma open data portal (Tacoma Open Data, 2025).

The equity index data, provided at the CBG level, includes most of the key variables, such as race, gender, age, education, economic status, infrastructure-related, transportation access, traffic, and environmental-related factors. Most variables are expressed as percentages unless otherwise specified. Table 2 summarizes all variables considered in this study. Bike lanes are measured as the percentage of a CBG's road network with designated bicycle facilities. Similarly, road miles with speed limits of 20–25 mph, 30–35 mph, and above 40 mph are represented in terms of percentages of the road network within a CBG. Land use variables represent the percentages of CBG land area designated as open space, commercial, industrial, or residential. Pavement condition is measured by the average Pavement Condition Index (PCI) of all road segments within a CBG, with scores ranging from poor (0–40%), fair (41–69%), to good (70–100%). Steep slopes were derived from 2018 bare earth Lidar data and refined by the City of Tacoma Planning and Development Services staff. Slopes are categorized into three classes: low (<25%), moderate (25–

40%), and high (>40%). These values represent the percentage rise of the surface and are linked to geologically hazardous areas as defined in Tacoma municipal code (TMC) 13.11.700, including erosion and landslide-prone zones. Slope data was averaged to assign one of the three categories to each CBG.

Table 2 Neighborhood-level data summary.

Variable	Description	Min	Max	Mean	Median	SD
Micromobility-related						
<i>Trips</i>	Average weekly trips	0.00	489.62	15.59	4.33	49.20
<i>TripRate</i>	Trip rate (average weekly trips per total population of a CBG)	0.00	378.00	12.25	3.00	38.26
<i>AverageDistance</i>	Average trip distance	0.00	3.93	2.03	2.10	0.72
<i>AverageTime</i>	Average travel time	0.00	31.03	13.54	13.61	5.03
<i>AverageSpeed</i>	Average travel speed	0.00	13.78	8.68	9.33	2.69
Population						
<i>PopTot</i>	Total population	612.00	2944.00	1406.12	1389.00	411.60
Race-ethnicity						
<i>White</i>	Percentage of non-Hispanic Whites	9.79	92.89	58.36	60.33	19.62
<i>Black</i>	Percentage of non-Hispanic Blacks	0.00	49.38	9.87	7.36	9.39
<i>Asian</i>	Percentage of non-Hispanic Asians	0.00	55.23	8.75	6.15	9.32
<i>NativeAmerican</i>	Percentage of non-Hispanic native Americans and Pacific Islanders	0.00	12.25	1.38	0.00	2.37
<i>OtherRace</i>	Percentage of non-Hispanic people of other races	0.00	48.59	10.26	9.04	7.39
<i>Hispanic</i>	Percentage of Hispanics	0.00	44.86	11.39	9.32	8.80
Gender						
<i>PopMale</i>	Percentage of the male population	36.97	71.84	50.11	50.00	5.93
<i>PopFemale</i>	Percentage of the female population	28.16	63.03	49.89	50.00	5.93
Age						
<i>Pop25Above</i>	Percentage of the population aged 25 years old and above	12.49	92.76	70.30	70.23	9.90
<i>PopUnder30</i>	Percentage of the population aged 29 years old and less	12.81	90.94	39.16	38.93	10.94
<i>Pop65Above</i>	Percentage of the population aged 65 years old and above	0.00	27.57	3.84	1.72	5.55
Education						
<i>HighSchoolMore</i>	Percentage of the population with at least a high school diploma	12.49	78.19	52.39	52.82	11.33
<i>HighSchoolLess</i>	Percentage of the population with less than a high school education	21.81	87.51	47.61	47.18	11.33
Income						
<i>IncomeLess50k</i>	Percentage of households in a CBG with an income below 50k	0.00	100.00	36.51	35.69	17.25

Variable	Description	Min	Max	Mean	Median	SD
<i>Income50kto75k</i>	Percentage of households in a CBG with an income between 50k and 75k	0.00	70.78	19.88	17.62	11.65
<i>Income75kto100k</i>	Percentage of households in a CBG with an income between 75k and 100k	0.00	45.99	13.86	12.48	8.06
<i>IncomeMore100k</i>	Percentage of households in a CBG with an income of 100k and more	0.00	75.64	29.76	25.24	16.66
Economic status						
<i>Poverty</i>	Percentage of the population earning less than the Federal Poverty Limit	0.00	49.00	13.58	10.00	11.08
<i>Unemployment</i>	Percentage of the unemployed population out of the total eligible workforce over 16 years of age	0.00	23.00	5.10	4.00	4.80
<i>RenterCost</i>	Percentage of all owners & renters in a CBG spending 30% or more of their income on housing costs.	0.00	100.00	46.99	46.73	21.52
Infrastructure-related						
<i>PavementCondition</i>	Average pavement condition of roadways within a CBG in %/Lower scores indicate poorer road quality	0.00	86.38	57.85	58.00	11.91
<i>BikeLanes</i>	Percentage of CBG's road network with a designated bike facility	0.00	18.59	1.56	0.00	3.50
<i>PedBikeTrails</i>	PedBike trails/Length of off-street pedestrian and bike paths, minus missing sidewalk segments, divided by CBG area	298.70	164.94	-50.29	-42.36	56.52
Transportation access						
<i>TransitAccess</i>	Percentage of a CBG's area within 1/4 mile of rail and bus service stops, within 3 miles of park and ride locations, and within micro transit areas divided by total CBG area	0.00	852.12	56.04	36.50	91.37
<i>VehicleAccess</i>	Percentage of the population with access to a household vehicle	50.00	100.00	91.81	95.00	9.78
Traffic exposure						
<i>Road20or25mph</i>	Percentage of roads with speed limits of 20 mph or 25 mph	0.00	100.00	56.16	57.35	15.16
<i>Road30or35mph</i>	Percentage of roads with speed limits of 30 mph or 35 mph	0.00	67.32	15.35	14.04	9.85
<i>Road40mphorMore</i>	Percentage of roads with speed limits of 40 mph or more	0.00	74.34	5.02	0.00	10.50

Variable	Description	Min	Max	Mean	Median	SD
<i>HeavyRoads</i>	Distance-weighted traffic along major roadways	25.11	3116.83	794.33	606.24	629.99
Terrain						
<i>LowSlopes</i>	Percentage of CBG with low slopes (<25%)	2.81	33.00	9.70	8.30	5.32
<i>ModerateSlopes</i>	Percentage of a CBG with moderate slopes (25%-40%)	0.00	8.49	1.19	0.56	1.50
<i>HighSlopes</i>	Percentage of a CBG with high slopes (>40%)	0.00	58.40	5.49	1.67	10.41
Environment-related						
<i>UrbanHeat</i>	Urban heat island effect - Average afternoon and evening temperature during a single day measurement to gauge relative island effects throughout the city	82.70	87.56	86.39	86.62	0.92
<i>Parks</i>	Percentage of CBG within 1 mile of community parks	1.05	3.00	2.53	2.67	0.47
<i>TreeCoverage</i>	Urban tree canopy - Percentage of a block group that is covered by an urban tree canopy	0.00	62.70	19.52	16.40	11.02
Land use						
<i>OpenSpace</i>	Percentage of a CBG with an open space	0.00	100.00	25.75	0.00	37.49
<i>Commercial</i>	Percentage of a CBG with commercial areas	0.00	100.00	20.53	1.46	31.99
<i>Industrial</i>	Percentage of CBG with industrial areas	0.00	96.78	2.61	0.00	13.47
<i>Residential</i>	Percentage of CBG with residential areas	0.00	100.00	29.92	12.45	37.14

2.3.3. Deriving Effects on Micromobility Usage with BQR

We applied BQR to examine the effects of sociodemographic, economic, and on-and off-road network characteristics on micromobility usage. We hypothesized that the effects of these characteristics including infrastructure, transportation access, traffic exposure, environment, terrain, and land use related differ according to micromobility usage levels with different population densities. BQR offers a significant advantage over traditional methods by relaxing the assumption of normality and enabling covariates to influence the entire conditional distribution, rather than focusing solely on the mean. In contrast, ordinary least squares regression estimates the impact of independent variables at the mean level, which can be skewed by the presence of extreme values. Moreover, quantile regression provides a more robust approach, allowing for the examination of how independent variables affect different levels or quantiles of micromobility usage. This approach is particularly relevant when independent variable effects vary across contexts, such as in CBGs with relatively uniform micromobility usage versus those with significant disparities. In other words, we hypothesized that the neighborhood-level independent characteristics (covariates, covariate/auxiliary variables) affect low-trip rate neighborhoods differently than medium and high-trip rate neighborhoods and vice versa. The model used for the BQR analysis is presented in Equation 1.

$$y_{i,p} = w_p x_i^T + e_{i,p} = \beta_1^p x_1 + \beta_2^p x_2 + \beta_3^p x_3 + \dots + \beta_n^p x_n + \varepsilon_{i,p} \quad (1)$$

where the dependent variable Y_i is the weekly trip rate; w_p is the weight vector for the p^{th} quantile; x_i^T is the vector of covariate variables; the covariate x_n includes all the independent variables, i.e., sociodemographic, economic, and all the infrastructure, transportation access, traffic exposure, environment, terrain, and land use variables; and $\varepsilon_{i,p}$ and β_n^p are the error term and variable coefficient at the p^{th} quantile (ranging between 0 and 1).

Equation 1 can be solved using the method of Barrodale and Roberts (1973) in minimizing the weight vector w_p as shown in Equation 2.

$$w_p = \underset{w_p}{\operatorname{argmin}} \sum_{i=1}^n \rho_p(y_i - w_p x_i^T) \quad (2)$$

where $\rho_p(\cdot)$ is the check function given by Equation 3 (Friederichs & Hense, 2007), and all other parameters are defined above.

$$\rho_p(u) = \begin{cases} u(p-1), & u < 0 \\ up, & u \geq 0 \end{cases} \quad (3)$$

In the BQR model, we considered five quantiles to capture different performance levels: 0.05, 0.25, 0.5, 0.75, and 0.95 as very low, low, medium, high, and very high quantiles. The posterior mean values were used as the estimates of the coefficients at each quantile. We assumed a normal prior distribution for the parameter β .

As part of the pre-processing, all independent variables were standardized. Since percentage variables are already on a uniform scale (0–100), standardizing them might not be necessary. However, the remaining variables, i.e., HeavyRoads and PedBikeTrails have a much larger and uneven range, which can dominate the model. Standardizing them brings them to a comparable scale with percentage variables. Therefore, we used z-score standardization to center and scale these two variables, ensuring they have a mean of 0 and a standard deviation of 1 without altering their original distribution shapes.

The first 100 iterations were discarded to improve stability and accuracy. Unlike traditional regression approaches, Bayesian regression does not provide p-values to assess significance. Instead, significance is determined by whether the coefficient distribution within a specified confidence interval includes zero. In this study, if a coefficient's distribution excludes zero within a 95% credible interval (CI), it is considered significant at the 0.05 level. Another key advantage of BQR is its ability to recover the entire distribution of coefficients across different quantiles, rather than just providing a point estimate with a confidence interval. The model was implemented using the R package *bayesQR* (Benoit & Van den Poel, 2017).

Given the prior distribution of the parameter set $\theta(w_p, \sigma_p, z_p)$, the joint posterior distribution of θ can be estimated using the Bayesian inference framework, as shown in Equation 4.

$$P(\theta|data) \propto P(data|\theta) \cdot P(\theta) \quad (4)$$

where $P(data|\theta)$ is the likelihood function.

2.4. Results and Discussion

2.4.1. Correlation Analysis

Figure 2 highlights the thirty most relevant and statistically significant correlations (p-value < 0.05), ranked by correlation strength, providing insights into key associations among CBG characteristics. To avoid redundancy, perfect correlations (strength = 1), such as those between PopFemale and PopMale or HighSchoolMore and HighSchoolLess, were excluded. Notably, the majority of correlations exhibited strong associations, with values exceeding 0.5.

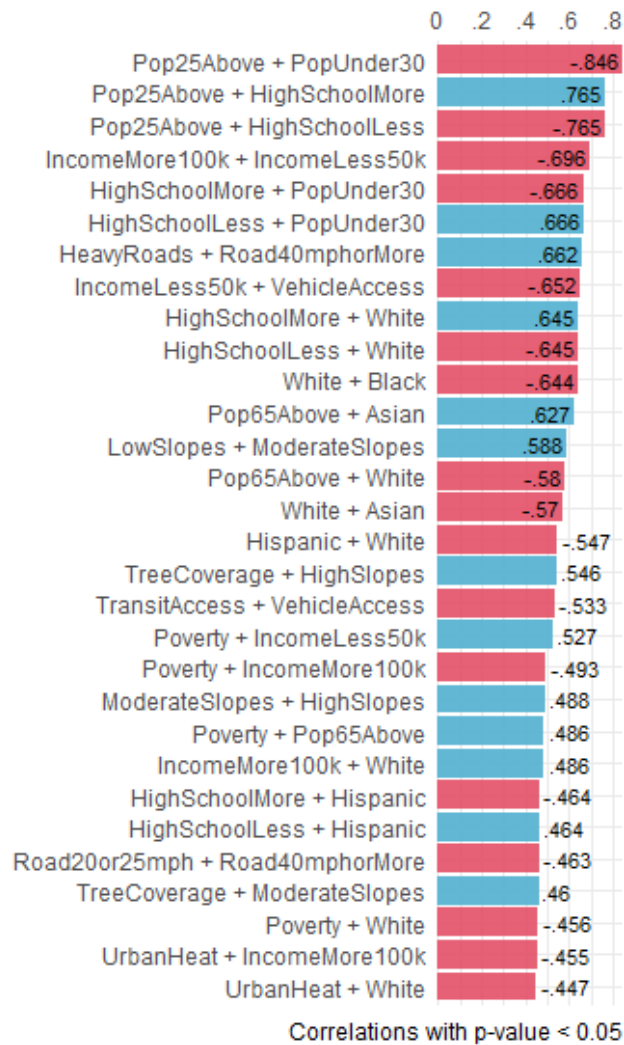


Figure 2 Top 30 rank-cross correlations.

Figure 2 reveals several strong negative correlations among neighborhood characteristics. Specifically, the percentage of individuals aged 25 and above (Pop25Above) is negatively correlated with both the percentage of individuals under 30 (PopUnder30) and the percentage of residents with less than a high school education (HighSchoolLess). Similarly, higher-income

households (IncomeMore100k) show a strong negative association with lower-income households (IncomeLess50k). Additionally, lower educational attainment (HighSchoolLess) is negatively correlated with the percentage of young residents (PopUnder30) and the proportion of White residents (White). Furthermore, racial composition exhibits strong negative relationships, with White residents negatively correlated with both Black and Asian residents. Other negative correlations include older adult populations (Pop65Above) and White residents, as well as transit accessibility (TransitAccess) and vehicle availability (VehicleAccess). This last negative correlation between suggests that areas with greater public transit availability tend to have lower vehicle ownership, reinforcing a potential reliance on public transportation.

Additionally, several strong positive correlations are observed. The relationship between heavy roadway traffic (HeavyRoads) and high-speed roads (Road40mphorMore) suggests that areas with higher traffic volumes tend to have more roads designed for faster travel, which may influence road safety and accessibility for micromobility users. The proportion of older adults (Pop65Above) is strongly associated with the Asian population (Asian), potentially reflecting demographic clustering. Similarly, low slopes (LowSlopes) are closely correlated with moderate slopes (ModerateSlopes), which is expected given natural terrain transitions. The positive correlation between tree coverage (TreeCoverage) and high slopes (HighSlopes) indicates that steeper areas may be less developed and more likely to retain natural vegetation. Lastly, the strong association between poverty levels (Poverty) and the proportion of lower-income households (IncomeLess50k) reinforces the connection between economic disadvantage and income distribution.

2.4.2. Spatial Analysis of Trip Rates

Figure 3 illustrates the distribution of trip rates across CBGs in Tacoma, using the median trip rate as a threshold. The majority of CBGs with trip rates below the median are concentrated in the North East, South End, and Eastside neighborhood council districts.

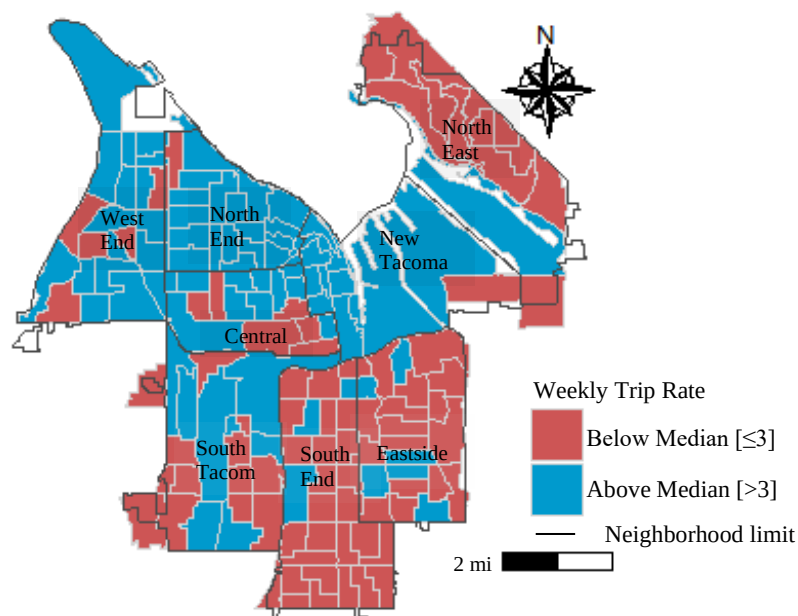


Figure 3 Trip rates across CBGs.

CBGs with above-median trip rates tend to have a higher proportion of White residents (+15.48%) and a slight increase in the “OtherRace” category (+1.00%), while Black (-1.36%), Asian (-1.63%), and Hispanic (-2.4%) populations are less represented. Gender distribution shows a slightly higher percentage of females (+1.52%) in above-median trip rate CBGs, with a corresponding decrease in the male population.

Table 3 Comparison of CBG characteristics below and above the median trip rate

Variable category (median)	Below median trip rate	Above median trip rate	Above vs. Below	
Race-ethnicity				
White	56.18	71.66	15.48	↑
Black	7.38	6.02	-1.36	↓
Asian	6.86	5.23	-1.63	↓
NativeAmerican	0.00	0.00	0.00	
OtherRace	8.70	9.70	1.00	↑
Hispanic	9.46	7.06	-2.4	↓
Gender				
PopFemale	49.54	51.06	1.52	↑
PopMale	50.46	48.94	-1.52	↓
Age				
PopAbove25	68.83	77.2	8.37	↑
PopUnder30	39.38	36.35	-3.03	↓
PopAbove65	2.09	0.62	-1.47	↓
Education				
HighSchoolLess	48.02	39.89	-8.13	↓
HighSchoolMore	51.98	60.11	8.13	↑
Income				
IncomeLess50k	34.58	38.61	4.03	↑
Income50kto75k	17.97	13.56	-4.41	↓
Income75kto100k	12.93	11.52	-1.41	↓
IncomeMore100k	25.24	24.5	-0.74	↓
Economic status				
Poverty	10.00	11.00	1.00	↑
Unemployment	4.00	5.00	1.00	↑
RenterCost	47.41	41.85	-5.56	↓
Infrastructure-related				
PavementCondition	59.00	51.50	-7.50	↓
BikeLanes	0.00	0.97	0.97	↑
PedBikeTrails	-44.72	-9.59	35.13	↑
Transportation access				
TransitAccess	32.62	58.13	25.51	↑
VehicleAccess	96	87	-9	↓
Traffic exposure				
Road20or25mph	58.21	55.58	-2.63	↓
Road30or35mph	13.89	15.67	1.78	↑
Road40mphorMore	0	0	0	
HeavyRoads	579.99	746.54	166.55	↑
Terrain				
LowSlopes	8.14	10.82	2.68	↑
ModerateSlopes	0.46	1.04	0.58	↑
HighSlopes	1.39	2.81	1.42	↑
Environment-related				
UrbanHeat	86.67	86.36	-0.31	↓
Parks	2.67	2.53	-0.14	↓

TreeCoverage	15.8	18.15	2.35	↑
	Land use (trip start)			
Open Space	0	9.98	9.98	↑
Commercial	2.77	0.41	-2.36	↓
Industrial	0	0	0	
Residential	12.22	20.41	8.19	↑
<i>Note.</i>				

Age and education levels also vary between the two groups of CBGs. CBGs with higher trip rates (above the median) have a greater proportion of residents over 25 years old (+8.37%) but a lower share of younger residents under 30 (-3.03%) and seniors over 65 (-1.47%). Additionally, these areas have a higher percentage of residents with more than a high school education (+8.13%), while those with only a high school education or less are more prevalent in below-median trip rate CBGs.

Income distribution reveals that households earning less than \$50k per year are slightly more common in high-trip-rate CBGs (+4.03%), while middle-income categories (\$50k–\$100k) are lower. Poverty (+1.00%) and unemployment (+1.00%) are also slightly higher in these CBGs, though renter cost burden is lower (-5.56%), possibly due to differences in housing affordability. Infrastructure and transportation access show notable contrasts. Pavement conditions are reported to be worse in above-median trip rate CBGs (-7.50%), but these areas have better bike lane availability (+0.97%) and significantly more pedestrian and bike trails (+35.13%). Transit access is much higher (+25.51%), while vehicle access is lower (-9.00%), suggesting greater reliance on public transportation.

Regarding road characteristics and traffic exposure, areas with higher trip rates have slightly more roads with speed limits of 30–35 mph (+1.78%) and significantly more heavy roads (+166.55). Terrain differences include more areas with low (+2.68%), moderate (+0.58%), and high slopes (+1.42%). Tree coverage is also slightly higher (+2.35%), which could impact urban heat and environmental factors.

Land use patterns indicate that high-trip-rate CBGs have significantly more open space (+9.98%) and residential land (+8.19%), while commercial land use is lower (-2.36%). These findings suggest that CBGs with higher trip rates may have more transit accessibility, pedestrian infrastructure, and residential density, while those with lower trip rates may have better road conditions, higher vehicle access, and a greater concentration of minority populations.

2.4.3. BQR Results

Table 4 presents the results of the BQR model. They provide insights into how different variables influence micromobility trip rates across different quantiles (very low, low, median, high, and very high). The Bayesian estimates in bold indicate significant results, meaning their 95% CI does not include zero.

Race-ethnicity. Native American and other race groups show significantly negative effects at higher quantiles, particularly in the very high trip rate quantile (0.95). This suggests that in areas with high trip rates, these racial groups tend to have significantly lower trip rates compared to others.

Table 4 BQR model results.

Variable	0.05 quantile (very low)			0.25 quantile (low)			0.50 quantile (median)			0.75 quantile (high)			0.95 quantile (very high)		
	Bayes Estimate	95% CI Lower	95% CI Upper	Bayes Estimate	95% CI Lower	95% CI Upper	Bayes Estimate	95% CI Lower	95% CI Upper	Bayes Estimate	95% CI Lower	95% CI Upper	Bayes Estimate	95% CI Lower	95% CI Upper
Race-ethnicity															
White	-2.54	-10.37	0.68	-0.58	-10.02	1.45	-0.53	-6.92	0.82	-0.22	-3.51	0.52	-0.19	-0.79	0.05
NativeAmerican	-4.97	-31.05	1.19	-1.60	-21.07	2.28	-1.83	-13.29	0.94	-1.94	-7.84	0.19	-3.61	-9.12	-2.33
OtherRace	-5.73	-16.42	-1.38	-2.04	-13.55	0.16	-1.35	-8.08	0.25	-0.59	-3.65	0.21	-1.93	-2.32	-1.49
Gender															
PopFemale	-5.24	-7.22	0.36	-4.43	-8.09	-0.95	-2.52	-4.82	-0.43	-1.06	-2.09	0.47	-0.13	-0.78	0.76
Age															
Pop25Above	0.51	-1.77	2.54	-1.27	-2.73	2.01	-0.59	-1.61	1.87	-0.05	-0.60	1.41	1.85	1.23	2.25
Pop65Above	-8.81	-26.34	0.29	-2.63	-22.17	2.32	-1.43	-13.08	1.19	-0.84	-6.68	0.51	-2.13	-4.08	-0.96
Income															
Income50kto75k	-0.29	-1.06	1.31	-1.22	-2.09	-0.32	-0.72	-1.14	0.05	-0.23	-0.61	0.34	0.98	0.54	1.61
Income75kto100k	-1.08	-2.95	0.52	-0.89	-2.02	1.19	-0.59	-1.37	0.28	-0.14	-0.83	0.84	0.08	-0.31	0.73
IncomeMore100k	0.43	-0.87	3.69	-0.25	-1.56	4.58	-0.20	-1.01	2.95	0.03	-0.56	1.61	-0.49	-0.87	1.07
Economic status															
Poverty	0.32	-0.49	1.51	-0.24	-0.85	2.13	-0.13	-0.45	0.97	0.30	-0.01	1.04	1.32	0.51	2.12
Unemployment	0.12	-1.04	1.83	0.43	-0.99	5.01	-0.12	-0.85	1.28	0.05	-0.50	1.15	-1.61	-2.77	-0.95
RenterCost	-0.58	-0.96	0.23	-0.48	-0.78	0.17	-0.27	-0.50	0.33	-0.12	-0.31	0.42	0.48	0.35	0.62
Infrastructure-related															
PavementCondition	0.56	-0.40	1.60	-0.35	-1.15	1.16	-0.52	-1.04	1.07	-0.38	-0.82	0.87	-0.43	-0.93	0.87
BikeLanes	-0.22	-1.33	1.62	-0.49	-2.82	0.29	-0.49	-4.96	0.50	-0.34	-1.03	0.28	1.26	-0.26	2.64
PedBikeTrails_scaled	16.09	-0.09	24.74	10.51	-0.27	26.64	6.89	-0.02	15.52	5.93	1.21	15.51	6.81	1.75	22.57
Transportation access															
VehicleAccess	1.75	1.25	2.17	0.52	-1.60	1.60	0.33	-1.55	1.45	0.30	-0.87	1.26	0.94	0.23	1.44
Traffic exposure															
Road20or25mph	-0.22	-0.79	0.52	0.23	-0.20	0.64	0.27	-0.02	0.70	0.28	0.00	0.66	-0.05	-0.28	0.20
Road30or35mph	1.21	-0.54	3.83	0.33	-0.31	2.85	0.43	-0.09	2.46	0.48	0.05	1.84	0.63	0.39	0.95
HeavyRoads_scaled	10.59	-1.39	55.82	5.42	-1.79	39.21	2.26	-2.06	19.06	2.91	-0.39	11.67	3.92	-0.22	8.10
Terrain															
LowSlopes	1.64	-0.13	4.54	0.61	-0.67	2.68	0.88	-0.38	2.11	1.70	0.57	3.78	3.13	2.49	4.15
ModerateSlopes	6.55	-0.56	23.87	-1.61	-8.05	5.89	-2.86	-7.13	0.01	-4.29	-13.70	-1.40	-1.20	-7.12	8.56
Environment-related															
UrbanHeat	2.53	1.29	3.27	2.79	1.57	3.22	2.54	1.16	3.11	3.09	1.09	3.81	1.96	0.79	2.68
Parks	3.79	-0.58	10.37	-0.98	-5.96	4.63	-1.33	-12.58	14.10	-4.11	-7.61	0.34	-24.50	-37.85	-2.79
TreeCoverage	-1.13	-2.73	0.20	0.07	-0.71	0.73	0.32	-0.21	1.33	0.54	-0.02	1.90	5.28	2.58	5.91
Land use															
OpenSpace	-0.06	-0.54	0.72	-0.08	-0.32	0.23	-0.08	-0.26	0.04	-0.02	-0.23	0.10	0.10	-0.13	0.29
Commercial	0.31	-0.26	1.43	-0.11	-0.44	0.94	-0.07	-0.32	0.32	-0.05	-0.25	0.07	0.00	-0.15	0.22
Industrial	-0.35	-1.27	0.36	-0.10	-0.71	0.15	-0.12	-0.85	0.12	-0.13	-0.60	0.04	-0.10	-0.30	0.14
Residential	0.33	-0.14	1.14	-0.07	-0.23	0.31	-0.05	-0.12	0.15	-0.02	-0.10	0.03	-0.04	-0.13	0.25

Gender and age. PopFemale has a significantly negative effect in the low and median quantiles, indicating that in CBGs with lower trip rates, a higher proportion of females is associated with fewer trips per capita. This suggests that gender disparities in travel behavior are more pronounced in lower-trip rate CBGs. Women tend to take fewer micromobility trips (bikeshare) than men (Reilly et al., 2022) and visit fewer unique locations overall (Gauvin et al., 2020). Older adults (Pop65Above) have a significant negative impact in the 0.95 quantile, meaning that in high-trip rate CBGs, older populations take fewer trips. Pop25Above is positively significant at the 0.95 quantile, suggesting that in high trip rate areas, more working-age adults contribute to increased travel.

Income and economic status. Middle-income households (\$50k-\$75k) have a significantly negative impact at the 0.25 and 0.50 quantiles, indicating that in CBGs with low and median micromobility trip rates, higher income is linked to reduced trip rates. This may reflect greater automobile dependency or less reliance on walking and public transit. Higher-income households tend to have lower micromobility trip rates, possibly due to greater car dependency (Younes & Baiocchi, 2023). Poverty is positively significant at the 0.95 quantile, suggesting that in high-trip rate CBGs, higher poverty levels are associated with increased travel. Unemployment is negatively significant at the 0.95 quantile, indicating that CBGs with higher unemployment see fewer micromobility trips. While micromobility has the potential to promote transport equity, its impact on accessibility and affordability for low-income users remains limited (Guan et al., 2024). Interestingly, multimodal travel is less prevalent among low-income adults compared to higher-income individuals, though low-income multimodal travelers tend to take more trips overall (Guan et al., 2024).

Infrastructure and transportation access. Pedestrian and Bike Trails have consistently positive and significant effects across multiple quantiles, particularly at the higher micromobility trip rates. This highlights the role of non-motorized infrastructure in encouraging travel behavior. Studies show that the built environment significantly impacts micromobility usage, with pedestrian-friendly infrastructure generating more trips (Younes & Baiocchi, 2023). However, usage in low-income and minority areas remains lower, suggesting a need for targeted interventions (Younes & Baiocchi, 2023). Concerns about improper parking of micromobility vehicles are often overstated, as motor vehicles impede access far more frequently (Brown et al., 2020). Vehicle access is positively significant at the very low (0.05) and very high (0.95) quantiles. Heavy roads show a positive effect on higher trip rate quantiles (0.75 and 0.95), suggesting that areas with more exposure to major roads tend to have higher travel rates.

Terrain and environmental factors. Urban Heat is significantly positive across all quantiles, suggesting that CBGs with higher heat exposure tend to have higher trip rates. This could be due to urban density effects or increased economic activity. Tree Coverage has a strongly positive effect at the 0.95 quantile, indicating that greener areas tend to be associated with higher travel rates, potentially due to increased pedestrian-friendliness or aesthetic appeal. In fact, street greenery enhances environmental aesthetics, safety, and comfort, while also improving air quality and reducing noise (Yu et al., 2024). Additionally, tree coverage in urban areas is linked to lower PM10 and PM2.5 pollution levels, contributing to improved air quality (Sierra-Porta et al., 2023).

Land use and traffic exposure. Lower slopes are positively associated with micromobility trip rates at higher quantiles (0.75 and 0.95), indicating that flatter CBGs promote higher mobility. Roads with 30-35 mph speed limits show a significant positive impact at higher trip quantiles, implying that moderate-speed road infrastructure supports increased micromobility. Parks show a significant negative impact at 0.95 quantile, suggesting that high-trip rate areas may not necessarily be linked with park proximity, possibly due to commercial or high-density land uses dominating. While parks generally show positive correlations with ridership (Bai & Jiao, 2020; Jafarzadehfadaki et al., 2024), their impact may vary across cities. High-density areas, downtown centers, and university campuses consistently demonstrate concentrated usage (Bai & Jiao, 2020; Jafarzadehfadaki et al., 2024). Factors positively influencing ridership include proximity to city centers, transit access, land-use diversity, and commercial areas (Bai & Jiao, 2020).

2.5. Summary of Findings and Recommendations

This chapter explored micromobility usage patterns in a mid-sized city and identified the associated factors. Tacoma, Washington, was selected as the study area. A BQR model was developed using Razor micromobility data to analyze these patterns and draw conclusions.

The findings indicated that shared micromobility in Tacoma is predominantly used by White residents, with lower representation among Black, Asian, and Hispanic populations. Women take fewer micromobility trips, especially in CBGs with lower trip rates. Younger adults (under 30) and seniors (65+) are underrepresented in high-trip-rate CBGs, whereas working-age adults contribute to higher micromobility use. Households earning less than \$50k per year are more common in high-trip-rate CBGs, but middle-income groups (\$50k–\$100k) are less represented. Addressing racial and gender disparities by implementing targeted outreach programs will help ensure accessibility for underrepresented groups, particularly women and minority residents.

The distribution of shared micromobility use suggests disparities based on race, income, and infrastructure access. Native American and other race groups have significantly lower trip rates in high-trip-rate CBGs. In low-trip-rate CBGs, female representation correlates with fewer micromobility trips, highlighting gender disparities. Higher-poverty areas tend to have more micromobility usage, yet multimodal travel remains less prevalent among low-income adults, indicating potential affordability and accessibility barriers. These findings suggest implementing pricing structures or subsidies to improve affordability for low-income users and expanding micromobility services in minority-dominated areas. Improve infrastructure in underserved areas to encourage ridership.

Many factors were found to affect micromobility ridership, including infrastructure, transportation access, road characteristics, terrain, land use, and traffic exposure. High-trip-rate CBGs have better bike lane availability, more pedestrian and bike trails, and higher transit access. Vehicle access is lower. Pavement conditions are worse in high-trip-rate CBGs. Investing in pedestrian and bike-friendly infrastructure while improving pavement conditions could enhance the micromobility experience. The findings also indicated that high-trip-rate CBGs have more roads with speed limits of 30–35 mph and more heavy roads. Areas with moderate slopes and increased tree coverage tend to see higher micromobility use. Improving micromobility access in areas with steep slopes by providing e-bike and e-scooter options and enhancing tree coverage to improve environmental comfort are measures that can foster micromobility use in Tacoma and other mid-sized cities.

High-trip-rate CBGs have more open space and residential land, but less commercial land. Parks do not significantly drive ridership in high-trip-rate areas. Encouraging mixed-use development and micromobility hubs near commercial areas, transit stations, and dense residential zones could be the solution to increase micromobility use. Poverty is positively correlated with higher trip rates, while unemployment negatively impacts micromobility use. Middle-income groups are less likely to use micromobility, possibly due to greater car dependency. The findings suggest expanding micromobility affordability programs and increasing outreach efforts to middle-income commuters who may be reliant on private vehicles.

3. INFLUENCE OF THE FACTORS ASSOCIATED WITH MICROMOBILITY CRASHES ON THE INJURY SUSTAINED

3.1. Introduction

Micromobility refers to a transportation mode characterized by the use of personalized mobility devices, such as electric bikes, electric scooters, and other personalized electric devices, for short-distance travel (Tian et al., 2022). This mode of transportation has gained popularity in urban and densely populated areas, offering multiple traffic and environmental benefits (Karpinski et al., 2022). Micromobility trips have exceeded half a billion trips since 2010, with a peak observed between 2018 and 2020 in the U.S. (NACTO, 2022). This increase in trips was concomitant with a rise in injuries associated with micromobility crashes, estimated at over 267,000 injuries. This correlates to the increase in emergency department visits that rose from 34,000 in 2017 to 77,200 in 2021 (Tark, 2022). Victims who are involved in these crashes are prone to sustaining prolonged injuries or even death (Stigson et al., 2021), as shown in **Error! Reference source not found. b** below, which depicts a rise in fatal micromobility crashes resulting in over 129 fatalities in the U.S. (Tark, 2022). These crashes typically do not yield one-time severity effects but are associated with long-term economic impacts since they majorly affect the economically productive age group (Bekhit et al., 2020; Ingstrup Nielsen et al., 2021).

Micromobility crashes result from a combination of different factors that influence their occurrence, leading to varying injuries of different severities. Understanding these contributing factors is a crucial aspect discussed in various studies, to establish associations with injuries that are likely to be sustained by the victim (micromobility rider). This will help identify factors that need to be considered to lower any risk of fatal or severe crashes. This study aims to determine the association of the factors contributing to the occurrence of micromobility crashes and their influence on the injury sustained by victims, ultimately identifying the most critical crash risk factors. Thus, this study focuses on elucidating how specific factors influencing micromobility crashes are associated with different types of injuries. Cluster correspondence analysis is employed to reveal multiple high-risk scenarios and contributing factors to micromobility crashes in Washington state.

3.2. Literature Review

Micromobility is one of the new modes of transportation, micromobility devices such as electric scooters and electric bikes are normally used to usher first and last-mile trips (Karpinski et al., 2022; Yang et al., 2020). Micromobility devices, mostly used as shared devices, have been able to accomplish more than half a billion trips since 2010 (NACTO, 2022), experiencing a significant rise in the number of trips during the COVID-19 pandemic (Tischler et al., 2023). Crashes involving micromobility have also increased significantly as the mode is becoming predominant. Observations show that per vehicle mileage traveled, micromobility has an injury rate of about 175 to 200 times higher than the state-wide and county injury rate for motor vehicles (Rix et al., 2021). Micromobility crashes are associated with multiple factors, whereas high-speed riding is one of the contributors to these crashes (Arellano & Fang, 2019; Cicchino et al., 2021). Young people face an elevated risk of involvement in micromobility crashes due to the popularity of this transportation mode in their age group (Hawes et al., 2019; CDOT et al., 2020; Yang et al., 2020). Specifically, people aged between 18 years and 40 years constitute a substantial portion of micromobility crash victims (Bekhit et al., 2020; Ingstrup Nielsen et al., 2021). Gender is another

contributing factor in micromobility safety, with males associated with a higher risk of being involved in fatal crashes due to riskier riding behavior (Cicchino et al., 2021; Shah et al., 2021). However, females are associated with a higher risk of experiencing falling incidents (Yang et al., 2020). Research also showed that micromobility crashes are likely to be more frequent in commercial, mixed use, and densely populated areas (Kalambay & Pulugurtha, 2022b).

Time and weather conditions when micromobility crashes occur influence these incidents. Most of the crashes occur during clear weather, especially during summer and on weekends, when there is an increased presence of pedestrians and vehicles due to sightseeing (Shah, 2020; Shah et al., 2021; Stigson et al., 2021). Micromobility crashes tend to occur between noon and 9 pm, with a higher risk of fatal crashes emerging during evening and late night. This also validates that most of the crashes occur due to visibility hindrance (Karpinski et al., 2022; Mathew et al., 2019; Shah et al., 2021). Surface type, roadway conditions, and intersection design are associated with the occurrence of crashes (Brownson et al., 2019). Still, it is argued that it becomes biased to term that micromobility drivers are exhibiting risky behavior when on the road because most of the roadway is not designed to accommodate them (Cicchino et al., 2021; Das et al., 2023; Shah et al., 2021). However, the interaction between a pedestrian and a micromobility rider is of high concern as it highlights the major safety concerns (Fitt & Curl, 2019; Tuncer et al., 2020). Pedestrians, particularly those with impairments, young children, and the elderly suffer severe secondary impacts following micromobility crashes (Sikka et al., 2019). Several studies have explored the impact of micromobility riders being impaired or under the influence of alcohol or drugs, but their contribution to crash occurrence appears to be less significant due to the challenges police face in identifying the level of intoxication (Beck et al., 2020; Blomberg et al., 2019; Cicchino et al., 2021; Karpinski et al., 2022). However, the low rate of use of protection gear, such as helmets, is one of the factors contributing to sustained injuries (Allem & Majmundar, 2019; Haworth et al., 2021).

Injuries sustained in crashes have different impacts on the lives of victims. The public health sector is increasingly concerned by the rise of micromobility injury crashes of 222% in the last few years. These injuries can have devastating consequences, such as lifelong disabilities and death (Aizpuru et al., 2019; Badeau et al., 2019; Trivedi et al., 2019; Trivedi et al., 2019). Over 40% of micromobility crashes necessitate hospital admission, and amongst these crashes, over 14% of the victims incur prolonged disabilities (Lavoie-Gagne et al., 2021). Different studies have focused on relating the severity of the crash outcomes to determining the factors, causes, and effects. For instance, most of the studies on crashes involving vehicles and micromobility users classified rider injuries sustained as either serious injuries or fatalities (Stigson et al., 2021). However, few studies have taken a different approach, classifying injuries not solely in terms of severity but also considering the specific circumstances of the crash (Lavoie-Gagne et al., 2021; Tischler et al., 2023). Most review studies primarily concentrate on categorizing the injuries themselves without delving into the factors leading to micromobility crashes or their potential associations with these types of crashes that are likely to result in sustained injuries. Injuries sustained can be classified based on the body parts affected, for example, head injuries, facial injuries, bone-related injuries, and chest or abdomen-related injuries (Toofany et al., 2021).

The significance of this study lies in its ability to establish a clear link between the injuries sustained and the factors that lead to micromobility crashes. This connection is crucial because it sheds light on the hazardous factors that contribute to these injuries. Conducting an effective study

in this context requires a well-defined methodology for both data collection and data analysis. Data collection in the realm of micromobility studies has been conducted in different ways. Some studies have used interviews as a method of data collection. For instance, Cicchino et al. (2021) interviewed 105 injured victims. However, it can be argued that this method introduced biases as the data obtained are influenced by the condition and state of mind of the individuals interviewed, and it often focused on the scenario narration of only one party that was involved in the crash. An alternative approach involves using the naturalistic method of data collection, which uses a video camera to capture real-time events in front of micromobility devices (White et al., 2023). While this method can effectively provide real-time video data, it is prone to missing out on some important surrogate factors that may not be in the direction of the crashes.

Text mining is another method that can be used to collect data, as demonstrated in the study by Yang et al., (2020). In this study, crash data was extracted from newspapers and other sources. Therefore, the text mining approach helps extract data from third-party sources that were likely not involved in the crashes thus reducing the risk of information bias. For instance, it can be used to extract information from crash narratives on the traffic police's website. Cicchino et al. (2021) and South et al. (2022) used logistic regression models to examine the relationship between the crash location and circumstances with the likelihood of sustaining injury. Their results were quantified using odd ratios. Das et al. (2023) used the perpetual cycle model with Haddon's matrix to identify the causal patterns of the micromobility crashes and recommend mitigation measures. These two analytical methods may not be flexible enough to examine the interrelation of different factors and determine how each factor influences specific response variables.

In recent years, studies have utilized cluster correspondence analysis (CCA), which is a form of unsupervised machine learning model that combines cluster analysis and correspondence analysis, providing specified numbers of clusters that are formed through the partitioning of individual attributes based on the categories found in the variables. CCA reduces the multicollinearity of the analysis data and provides a low-dimensional projection of the data (Rahman et al., 2022; Sun & Zhou, 2023; Van de Velden et al., 2017). The main benefit of cluster correspondence analysis is accounting for multiple categories in the variable providing an upper hand for the model relative to other models discussed.

3.3. Materials and Methods

3.3.1. Data Description

The crash data used for this study were retrieved from the Washington Department of Transportation (WSDOT). The crashes analyzed occurred between 2017 and 2022. However, the crash data does not have an attribute that indicates if a micromobility was involved. Therefore, the research team established the attribute by reading the crash narrative for each crash that was recorded and identifying the crashes that directly mentioned that a micromobility user was involved. A total of 110 crashes were identified that directly involved the micromobility devices whereas

Table 5 shows the summary of the data obtained.

Table 5 Summary of micromobility crashes.

Variable	Count (Percentage)
Day	
Weekday	91 (82.7%)
Weekend	19 (17.3%)
Road users at fault	
Micromobility at fault	50 (45.5%)
Vehicle at fault	60 (54.5%)
Junction	
Intersection	68 (61.8%)
Roadway	42 (38.2%)
Weather	
Clear	53 (48.2%)
Not clear	57 (51.8%)
Road_Surface	
Dry	94 (85.5%)
Wet	16 (14.5%)
Lighting	
Dark	16 (14.5%)
Daylight	94 (85.5%)
Vehicle_Type	
Other	62 (56.4%)
Passenger car	48 (43.6%)
Driver_Action	
Going straight	30 (27.3%)
Stopped, starting in a traffic lane, or merging	15 (13.6%)
Turning, changing lanes, or overtaking	65 (59.1%)
Traffic_Control	
No control	56 (50.9%)
Signal, stop sign, or yield	54 (49.1%)
Driver_Age	
30-64	61 (55.5%)
65+ (Max 81)	14 (12.7%)
Under 30 (Min 16)	35 (31.8%)
Driver_Gender	
Female	53 (48.2%)
Male	57 (51.8%)
Driver_Circumstance	
Did not grant ROW	26 (23.6%)
Improper maneuver, distraction, or other	84 (76.4%)
Micromobility_Action	
Riding against traffic	18 (16.4%)
Riding with traffic	34 (30.9%)
Turned, fell, or pushed into the path of the vehicle	37 (33.6%)
Xing or entering a roadway	21 (19.1%)
Micromobility_Age	
30+ (Max 72)	58 (52.7%)
Under 30 (Min 10)	52 (47.3%)
Clothing_Visibility	
Dark	41 (37.3%)
Light	18 (16.4%)

Variable	Count (Percentage)
Mixed	51 (46.4%)
Micromobility_Gender	
Female	23 (20.9%)
Male	87 (79.1%)
Micromobility_Circumstance	
Did not grant ROW	14 (12.7%)
Disregard signs/signals or exceeding safe speed	14 (12.7%)
Improper maneuvering or distracted	13 (11.8%)
Other	69 (62.7%)
Micromobility_Infrastructure	
Bike route	25 (22.7%)
Crosswalk	19 (17.3%)
Roadway	30 (27.3%)
Shoulder or sidewalk	36 (32.7%)
Helmet_Use	
No	54 (49.1%)
Yes	56 (50.9%)
Injury_Sustained	
Chest/Abdomen injury	8 (7.3%)
Head injury	15 (13.6%)
Orthopedic injury	41 (37.3%)
Skin or no injury	46 (41.8%)

Table 5 indicates that 82.7% of the micromobility crashes occurred during weekdays and 17.3% of the crashes occurred during weekends. The data show that about 54.5% of the crashes found the vehicle to be at fault, while 45.5% of the crashes found the micromobility user to be at fault. Furthermore, about 61.8% of the micromobility crashes occurred at intersection areas, while 38.2% occurred on different parts of the roadway. This indicates that micromobility is more vulnerable in the intersection areas. The data shows that the majority of micromobility crashes (51.8%) occur in weather conditions that are not clear conditions, and about 48.2% of micromobility crashes occur in clear weather conditions. However, the data indicates that 85.5% of the crashes occurred in dry road surface conditions and 14.5% of the crashes occurred in wet road surface conditions.

Data show that 85.5% of micromobility crashes during daylight time while a small proportion of micromobility crashes, about 14.5%, occurred during the dark time of the day (indicating nighttime). On the other hand, passenger cars were observed to be involved in 43.6% of the micromobility crashes, and most of the crashes (about 56.4%) involved other types of vehicles such as trucks, buses, and semi-trailers. Furthermore, from the data summary in

Table 5, we obtained more personal information, the driver's circumstances, and the driver's actions (the word "driver" will be referred to as the vehicle driver). For instance, data shows that the most prominent driver action that contributes to micromobility crashes was observed to be turning, changing lanes, or overtaking, contributing to 59.1% of crashes, while actions such as stopping, starting in a traffic lane, or merging contribute to 13.6% of the crashes and 27.3% of the crashes were caused by drivers going straight ahead.

The data show that circumstances that drivers go through leading to crashes include improper manoeuvring, distraction, or other contributing to 76.4%, and another circumstance involves drivers not granting the right of way, which led to 23.6% of the micromobility crashes observed. The data indicate that 50.9% of the micromobility crashes occurred on road sections with no traffic control, while 49.1% occurred in areas with either traffic signals, stop signs, or yield signs. Furthermore, the data shows that male drivers were involved in 51.8% of the micromobility crashes comparable to 48.2% of the micromobility crashes that involved female drivers. On the other hand, drivers aged between 30-64 years old were observed to be involved in 55.5% of the micromobility crashes, while drivers aged less than 30 years old and greater than 65 years old were involved, proportioned to about 31.8% and 12.7% of the micromobility crashes respectively.

Table 5 summarizes micromobility users' information and behavioral patterns that have contributed to the occurrence of these crashes. For instance, 33.6% of the crashes involved a micromobility user that made a turn, fell, or pushed into the path of the vehicle, also 30.9% of the crashes involved micromobility users that were riding with traffic and some of the micromobility actions found were riding against traffic contributing to 16.4% while micromobility user found to crossing or entering a roadway contributed to 19.1% of the micromobility crashes. The data show that 52.7% of the micromobility users involved in the crashes were over 30 years old and about 47.3% of the micromobility users were below 30 years old. Furthermore, the data indicates that 79.1% of the micromobility users involved in the crashes were male and 20.9% of the micromobility users were female. Data about the visibility of the clothing that a micromobility user wore during the crash was collected. The data indicates that 46.4% of the micromobility users wore mixed-colored clothing, 37.3% wore dark-colored clothing, and 16.4% wore light-colored clothing.

Data show that different circumstances led to the involvement of micromobility users, where 12.7% of the users did not grant the right of way to vehicles and another 12.7% of the users disregarded the signs and traffic signals or the posted speed limit, while 11.8% of the micromobility crashes involved micromobility users performing improper maneuvering or being distracted. However, about 62.7% of the crashes were caused by other different circumstances. The data summary also shows that 32.7% of the micromobility users were using the shoulder or sidewalk at the time of the crash, while 27.3% of the micromobility users were using the roadway. Furthermore, 22.7% of the micromobility users were using the bike route when they were involved in the crash, and about 17.3% of the micromobility users were using the crossing walks when they were involved in the crash. The data shows that 50.9% of the micromobility users were wearing a helmet involved in the crash and 49.1% of the micromobility users were not wearing helmets at the time of the crash.

From all the information collected about the circumstances and actions that led to the crash occurrences, the data also show the crash outcomes in terms of the individual injuries sustained by the micromobility users, whereas the data show that 41.8% of the micromobility users sustained skin injuries (such as bruises) or no injuries. The data show that 37.3% of micromobility users sustained orthopedic injuries, while 13.6% of micromobility users sustained head injuries, and about 7.3% sustained chest/abdomen injuries. Based on the crash-level data, we have classified injuries sustained to their respective crash severity outcomes, as shown in Figure 4.

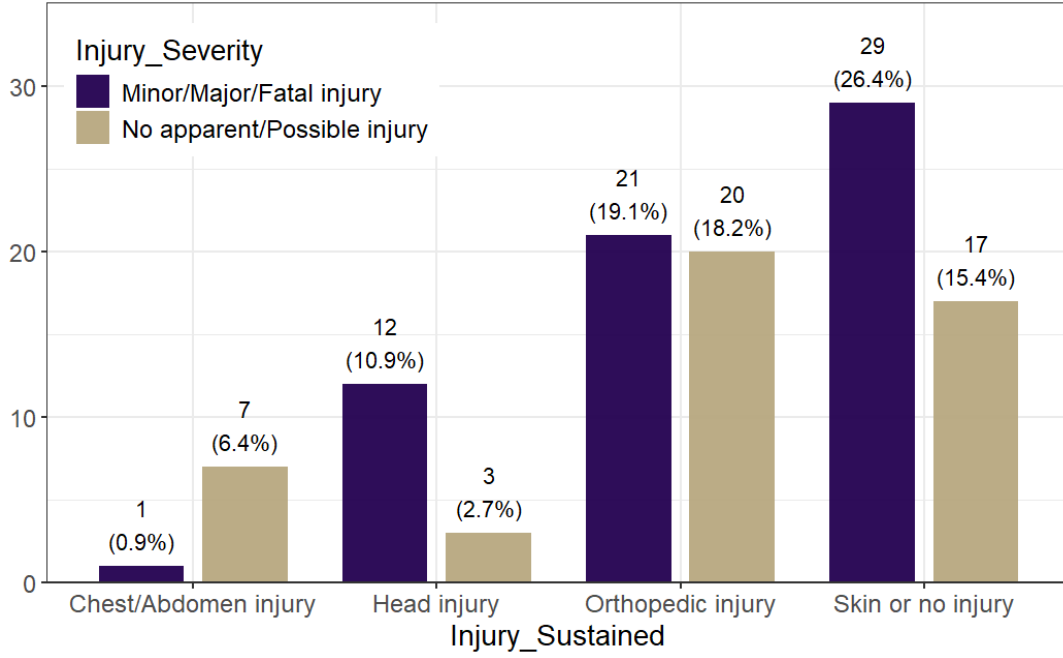


Figure 4 Injury severity per injury sustained.

3.3.2. Methods

CCA integrates K-means clustering with simple correspondence analysis to group crash characteristics based on similarities. This method has gained significant attention across various fields, including transportation (Cabral & Kim, 2020; Das, Tabesh, et al., 2023). By optimally scaling values into groups, CCA highlights key factor associations within each cluster while maximizing variance between clusters (Van de Velden et al., 2017). In this study, CCA is implemented using the R package *clustrd* (Markos et al., 2019). A brief overview of CCA is provided below.

Crash data intended for clustering consists of n reports and p categorical variables (e.g., race or other attributes) organized into a matrix Z with dimensions $n \times Q$, where $Q = \sum_{j=1}^p q_j$ and $Z_j 1_{q_j} = 1_n$. Cluster membership is represented through an indicator matrix Z_K , where K denotes the number of dimensions. A table F with a distribution of cluster memberships across the different variable categories can be created to examine the relationship between the clusters and the categorical variables. This is formulated as $F = Z'_K Z$, where Z_K is the $n \times K$ indicator matrix signifying cluster membership. By applying a correspondence analysis framework to this table, optimal scaling values for both clusters and categories are obtained. Clusters are formed based on the distribution of categorical variables in the dataset, while categories with differing distributions across clusters are optimally partitioned. The optimal cluster allocation Z_K is mathematically expressed as shown in Equation 5 (Van de Velden et al., 2017).

$$\max \phi_{clusca}(Z_K, B^*) = \frac{1}{p} \text{trace} B^{*'} D_Z^{-1/2} Z' M Z_K D_K^{-1} Z'_K M Z D_Z^{-1/2} B^* \quad (5)$$

where,

D_K is the diagonal matrix of $Z'_K Z_K$,

$$M = I_n - 1_n 1_n' / n,$$

D_Z is the diagonal matrix such as $D_Z 1_Q = Z' 1_n$, and

B represents the column coordinate matrix, such as $B^* = \frac{1}{\sqrt{np}} D_Z^{1/2} B$ and $B^{*'} B^* = I_K$

The optimization problem, which aims to maximize $\Phi(Z_K, B^*)$ with respect to Z_K , can be restructured as a K-means clustering problem for a fixed B^* . This transformation leads to an objective function for K-means, as expressed in Equation 6 (Van de Velden et al., 2017). In this formulation, G represents a matrix containing cluster means, while other relevant parameters remain consistent with the definitions provided earlier.

$$\min \Phi_{clusca}(Z_K, G) = \left\| \sqrt{\frac{n}{p}} M Z D_Z^{-1/2} B^* - Z_K G \right\|^2 \quad (6)$$

When implementing CCA in R (R Core Team, 2024), the initial number of clusters and dimensions must be specified. To determine the optimal values, the *tuneclass* function is used, which relies on well-established distance-based metrics such as the Average Silhouette Width (ASW) index and the Calinski-Harabasz (CH) index. Careful selection of these parameters is crucial to enhancing cluster separation and ensuring the identification of meaningful groups. For a more comprehensive discussion of the CCA methodology, readers may refer to Van de Velden et al. (2017).

3.4. Results and Discussion

3.4.1. CCA Results

The number of clusters was initially selected using K-means clustering and repeated multiple times. The analysis of micromobility crashes resulted in three distinct clusters, each representing a specific proportion of the dataset. Cluster 1 accounted for approximately 41.8% of the crash data, Cluster 2 comprised 37.3%, and Cluster 3 included the remaining 20.9%. Each cluster revealed unique patterns and insights, which are discussed in the following sections.

Figures 5-7 show the top 20 variables with the highest standardized residuals (whether positive or negative in absolute value) within each cluster. These residuals highlight variable categories that deviate the most—either positively or negatively—from the expected independence condition. A positive residual indicates that a variable appears more frequently than average within a cluster, whereas a negative residual suggests a lower-than-average frequency. Higher positive residuals signify a stronger association with the cluster, contributing more significantly to its segmentation. This helps identify key factors influencing the types of injuries sustained by micromobility users. Among the three identified clusters, our discussion will focus on the variable categories with positive standardized residuals.

Cluster 1 (C1) - Circumstance and action leading to a skin or no injury

The findings for the first cluster (C1) are summarized in Figure 5. This cluster accounts for the largest share of crash data. Several variable categories exhibit positive standardized residuals, including non-junction (roadway) locations, micromobility users on the shoulder or sidewalk, uncontrolled/no signalized intersections, micromobility users making a turn, falling or being

pushed into a vehicle's path, female drivers, and injuries categorized as skin injuries or no injury. Additionally, C1 is characterized by micromobility users over the age of 30, vehicle drivers engaging in improper maneuvers, distraction-related incidents, and other micromobility-related factors. C1 suggests that crashes in this category frequently involve female drivers who were either distracted or executed an improper maneuver. Moreover, micromobility users in these crashes were often over 30 years old, using the shoulder or sidewalk, and sustained minor or no injuries. This finding aligns with Zhang et al. (2023) who reported that shared sidewalks between pedestrians and micromobility users increase the risk of collisions among vulnerable road users and motorists commuting near these areas. Additionally, improper maneuvers and speeding have been identified as key contributors to vehicle-related crashes (Das et al., 2023; Xu et al., 2022).

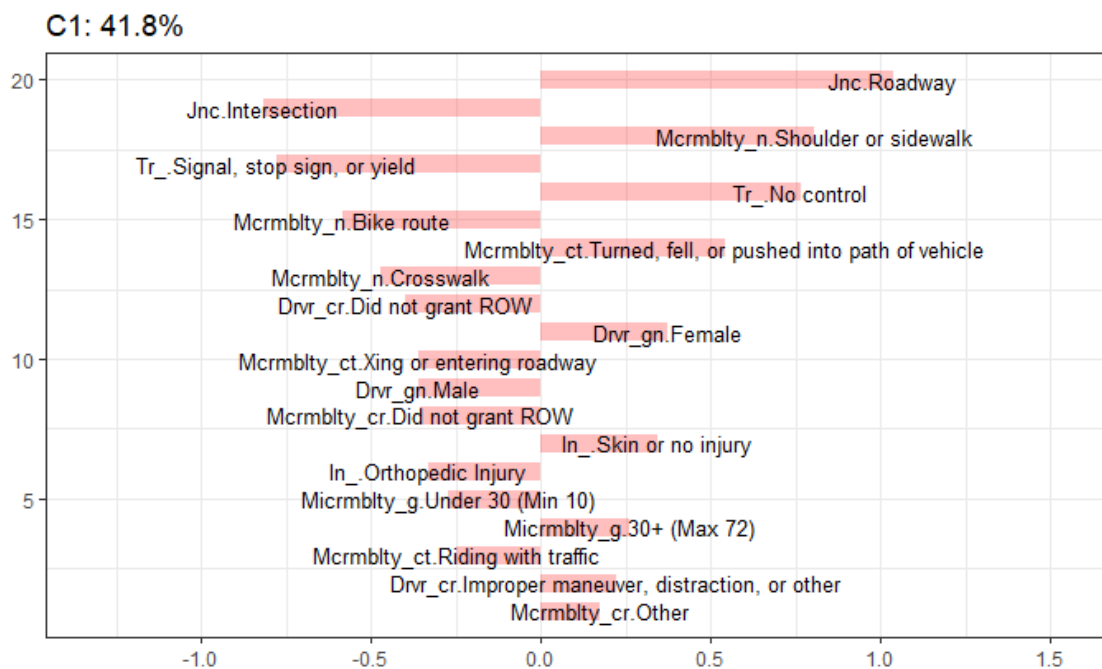


Figure 5 Top 20 largest standard residuals for cluster 1.

Cluster 2 (C2) - Circumstance and action leading to an orthopedic injury

The second cluster (C2), illustrated in Figure 6, represents crashes occurring at intersections controlled by traffic signals, stop signs, or yield signs. Many variable categories within this cluster are closely related, as indicated by their positive standardized residuals on the right side of the figure. These include micromobility users on bike routes, riding with traffic, vehicle drivers failing to grant the right-of-way, signalized or stop-controlled intersections, junctions categorized as intersections, orthopedic injuries, vehicle drivers aged over 65 (up to 81 years), and male drivers. C2 strongly correlates with crashes involving older male drivers (over 65 years) who frequently failed to yield the right-of-way to micromobility users. Additionally, micromobility users in this cluster were often riding in the same direction as traffic on bike routes and were more likely to sustain orthopedic injuries. This finding aligns with existing research, which highlights that sideswipe collisions are a prevalent crash type for micromobility users and other vulnerable road users traveling alongside vehicular traffic (Guesneau et al., 2024).

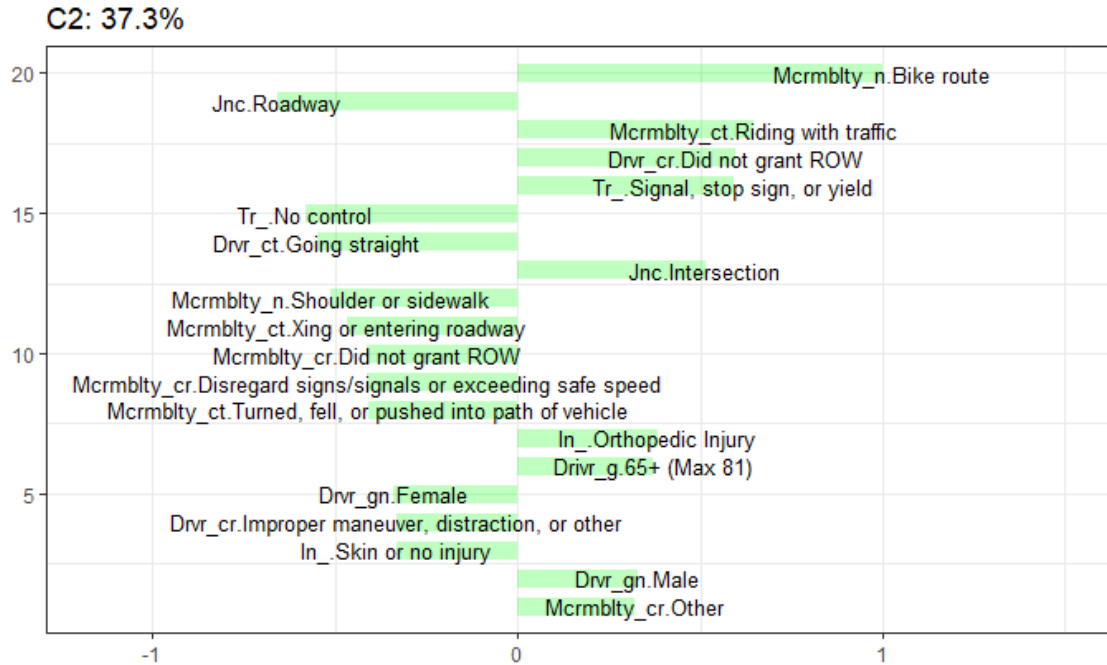


Figure 6 Top 20 largest standard residuals in cluster 2.

Cluster 3 (C3): Micromobility action at an intersection

The findings from the final cluster (C3) are presented in Figure 7, highlighting crashes that occurred at crosswalks within intersections controlled by signals, stop signs or yield signs. This cluster includes several key variable categories, such as micromobility users crossing or entering the roadway, failing to yield the right-of-way, using crosswalks, disregarding traffic signs/signals, or exceeding safe travel speeds. Other associated variables include vehicle drivers traveling straight, intersection junctions, wet road conditions, drivers aged 30–64 years, and micromobility users under 30 years old (as young as 10 years old). C3 shows a strong connection to crashes where micromobility users, predominantly under 30 years old, entered or crossed the roadway without obeying traffic signals or signs. Additionally, these users were observed to exceed safe travel speeds and failed to yield to vehicle drivers, contributing to the crash occurrences. The results further indicate that vehicle drivers involved in these incidents were generally between 30 and 64 years old and were traveling straight on the roadway at the time of the crash. These findings align with previous research, which identifies intersections as high-risk locations for severe micromobility crashes (Sanjurjo-de-No et al., 2023). Additionally, behavioral factors such as disregarding traffic rules and exceeding speed limits significantly increase micromobility users' vulnerability to severe crash outcomes (Guesneau et al., 2024; Sanjurjo-de-No et al., 2023).

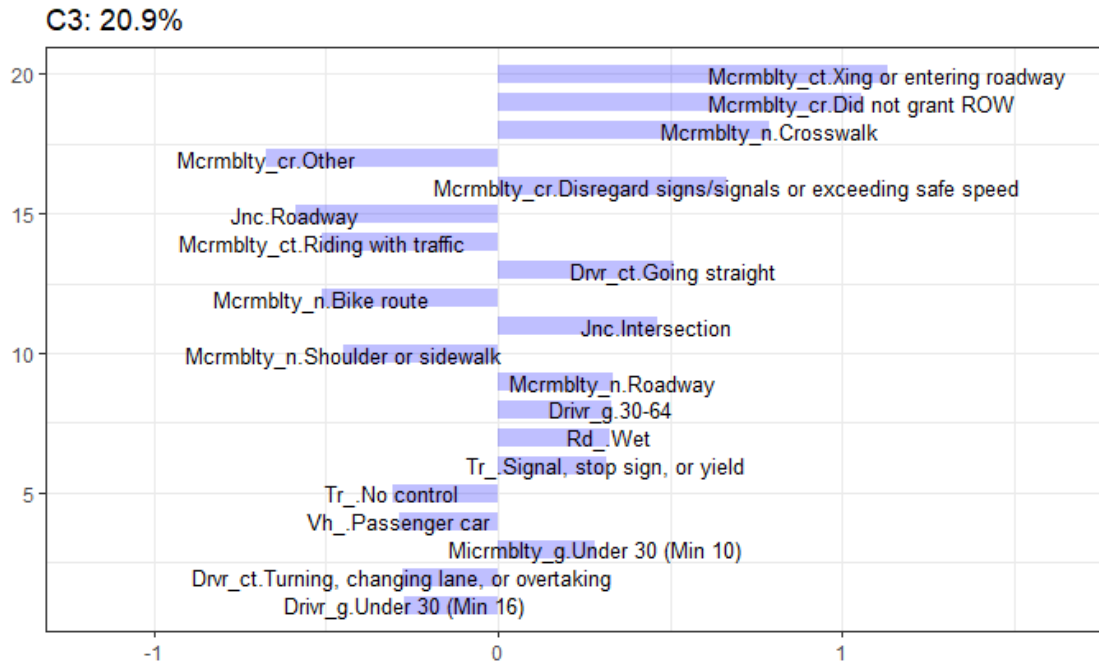


Figure 7 Top 20 largest standard residuals in cluster 3.

3.5. Summary of Findings and Recommendations

Micromobility is a relatively new mode of transportation, and its users are considered to be vulnerable road users. Due to the rapid increase in micromobility usage, there is a surge in crashes involving these users, leading to various sustained injuries. Different types of injuries sustained lead to different scales of crash severity outcome. The study categorized different types of injuries sustained by the victims to determine different factors that influence or cause the victims to sustain such injuries. The study utilized the micromobility crash data for crashes that occurred between 2017 and 2023 in Washington state. The study utilizes a comparatively new categorical data analysis approach combining cluster and correspondence analyses. The crash data are analyzed to produce three clusters where the top twenty residuals (both positive and negative) are retrieved per each cluster. Furthermore, it utilizes the estimation of top positive residuals, demonstrating the correlation between various variable categories, indicating the most pervasive crash scenario that led to micromobility users sustaining injuries. The cluster correspondence analysis approach utilizes automated data segmentation that abides with the dimensional reduction in categorical data, differentiating itself from other subjective methodologies.

The three clusters provide interesting insights into different factors that led micromobility users to sustain a particular injury. Through associating different actions, circumstances, and conditions, the study identifies different factors when combined that led to micromobility users sustaining a particular injury. For instance, the finding in cluster 1 shows that skin injuries or no injuries to micromobility users are associated with improper maneuvers performed by drivers who are potentially distracted and are most associated with female drivers. Furthermore, the second cluster indicates that orthopedic injuries are associated with the driver failing to yield the right of way to the micromobility user. Lastly, the third cluster did not specify a particular injury sustained by the micromobility user, but rather, the cluster provides insights on violations that the micromobility users perform, such as riding above safe travel speed. Generally, the findings of the study show

that not only are vehicle drivers the cause of these crashes but also that the micromobility users violate safety measures. Therefore, mitigation measures to be implemented should account for both micromobility users and non-micromobility users.

The findings of this study contribute to the development and advocacy of specific measures aimed at reducing various types of crashes involving drivers and micromobility users across diverse demographic characteristics, including age and gender. Additionally, the study sheds light on the specific circumstances and reasons behind micromobility crashes in Washington State. This understanding is crucial for designing targeted interventions to enhance road safety. While substantial research has focused on pedestrian-vehicle and vehicle-vehicle crashes, there remains a substantial need for comprehensive exploration in the realm of micromobility crashes. Further investigations can provide valuable insights into the unique dynamics of these incidents, informing future safety policies and initiatives. The main limitation of the study is the fact that crashes are underreported for micromobility users.

4. ESTABLISHING A STANDARD OF EQUITY IN SHARED MICROMOBILITY

4.1. Introduction

Shared micromobility has seen a surge in popularity in the U.S., with over half a billion trips taken since 2010 (NACTO, 2023). Micromobility devices have promising potential to solve current transportation challenges, such as first/last-mile trips, which refer to the gap between the nearest public transit station and the rider's destination (Hong et al., 2022). Compared to cars, they also provide users a way to avoid traffic congestion, reduce the time spent on short-distance trips, reduce their environmental impact, have more connection to the outdoors, have maneuverability, versatility, ease of use, and a lower initial cost barrier (Bozzi & Aguilera, 2021).

The Federal Highway Administration defines micromobility devices as “any small, low-speed, human- or electric-powered transportation device, including bicycles, scooters, electric-assist bicycles, electric scooters (e-scooters), and other small, lightweight, wheeled conveyances” (FHWA, 2024). Shared micromobility refers specifically to micromobility services using a short-term rental model, most commonly e-scooters and e-bikes. Shared micromobility can take the form of either docked or dockless services (FHWA, 2024). Docked services involve charging stations where users can pick up the vehicles and return them once their trip is completed. Dockless services are much more decentralized, where users employ an app to identify the nearest device (typically somewhere along the sidewalk), rent the device, take it to the desired destination, and end their trip once done.

The literature confirms that micromobility is beneficial for low-income brackets and predominantly non-White neighborhoods and communities and is even preferred over docked-based bikeshare services, with ridership highest among these groups and in urban centers (Sanguinetti & Alston-Stepnitz, 2023; Stowell, 2020). Rising costs, however, may push some users to abandon these services. Most shared micromobility services operate on a plan that charges users per minute, and with long-term regular use, this can come to rival or even overtake the cost of other transportation methods (Bai & Jiao, 2024; Su et al., 2024). In Santa Monica, for example, the cost of shared mobility services is beginning to equal the cost of using a car (Stowell, 2020). Such price increases can discourage use among the disadvantaged groups who have the most demand for it.

There are also discrepancies in the primary demographic of various micromobility forms, with some literature stating the main users are young, educated, White men, while others indicate that low-income and minority communities have the highest ridership (Hong et al., 2022; Sanguinetti & Alston-Stepnitz, 2023; Stowell, 2020). This discrepancy could be due to issues with data-representativeness or possibly variations in the users of different device forms themselves (e.g., e-scooters vs. bicycles). Disadvantaged communities being left out of the data used in planning means they are not given access to the resources required to use the services being studied. Because they lack resources, ridership in these areas diminishes, meaning when they are surveyed next, the results still show a lack of ridership in the area, and the cycle continues. This type of representation cycle contributes significantly to the inequity of shared micromobility services and must be addressed if the industry is to be made more equitable. Transportation planning thus far has focused on distributing mobility services based on equality and population density rather than equity and

meeting actual need/demand (Sanguinetti & Alston-Stepnitz, 2023), further contributing to inequity.

There are several areas of improvement to be made in the existing policies and programs in the industry. Some cities are adopting programs specifically geared toward addressing inequities in shared micromobility, usually in distribution and cost, such as alternative payment methods for users without smartphones or bank accounts (Stowell, 2020). Such programs represent significant progress in making shared micromobility more equitable but suffer from the same problems of unrepresentative data, ineffective regulation, and lack of suitable infrastructure (Hong et al., 2022; Sanguinetti & Alston-Stepnitz, 2023; Stowell, 2020). One such equity program in Seattle, WA, set a distribution requirement that vendors must deploy 10% of their fleet to Environmental Justice Communities Areas of Focus (otherwise called Equity Focus Areas or EFAs). As investigated by Hong et al. (2022), however, this program largely fails to adequately address the areas with the highest need or effectively regulate scooter distribution, with the 10% requirement being shared across three different EFAs and could be fulfilled by just one of them. Some literature has found that expanding access to data to transportation advocates has a beneficial effect on equity and effectiveness in advocacy and suggests that data sharing be included in a municipality's efforts to promote equity (Sanguinetti & Alston-Stepnitz, 2023). One consistent suggestion shared by a significant portion of studies is an increase in the quality, density, and availability of bicycle infrastructure. Several of them suggest that bicycle infrastructure is directly tied to micromobility usage, and improvements in this area would increase ridership and ease worries about safety (Hong et al., 2022; Sanguinetti & Alston-Stepnitz, 2023; Stowell, 2020).

To date, most previous research has focused on the usage of micromobility devices, concerned with the viability of micromobility as a solution to the first/last mile problem or as an alternative to other transportation methods (Bach et al., 2023; Bozzi & Aguilera, 2021). Some studies also explore potential methods to increase the usage of micromobility in cities (Hong et al., 2022; Sanguinetti & Alston-Stepnitz, 2023). Few studies were found focusing explicitly on equity (Caspi, 2022; Su et al., 2024), and of those, even fewer had explicit definitions of equity or equitability or visions of equity specifically within a micromobility context (Bach et al., 2023). However, in reviewing this literature, we identified a significant and glaring issue that undermines the effective and holistic development of policy solutions for shared micromobility programs: the absence of a clear definition and framework for what micromobility equity entails. To address this knowledge gap, our study aims to answer the following three research questions (RQs) that seek to foster a deeper understanding of the core tenets and practices for the promotion of equity in shared micromobility programs.

- RQ1. How do regulatory agencies and service providers currently conceptualize equity, and how should it be defined?
- RQ2. What are these organizations doing to ensure their projects are equitable? In particular, what methods do they use to evaluate equitability?
- RQ3. What are the biggest barriers/successes to implementing equitable shared micromobility that we can learn from?

To answer these research questions, we engaged micromobility and active transportation experts in a survey where they were asked to define and operationalize equity within shared micromobility.

Using the survey data, we aimed to lay a foundation for future research on equity in shared micromobility and to offer guidelines for organizations looking to implement or promote equity within their services.

4.2. Methods

Data collection for this study centered on an online Qualtrics survey involving professionals working for governmental organizations in the micromobility or active transportation sector within the U.S. Selected participants were contacted via email, which included an explanation of the study and a link to the survey. Participants completed the survey at a self-directed time.

Participants were identified and selected through a snowball sampling process through word-of-mouth recommendations from an initial list of contacts identified with our partners at the Washington State Department of Transportation (WSDOT). The research team started by reaching out to a select group of professionals within WSDOT. These participants were met with over Zoom, given an explanation of the goals of the survey, and asked if they would like to participate. They were also asked if they had recommendations for other survey candidates. After the Zoom information session, the research team was directed to specific programs, WSDOT directories, and NGOs. After these leads were exhausted, the research team inquired into other NGO committees and councils on micromobility, bicycles and pedestrians, or active transportation. The chairs or liaisons of these committees were contacted and asked if they would be willing to use their position to disseminate the survey within their groups. Therefore, a majority of survey respondents were not contacted directly by the research team. Through this participant selection process, 35 were asked to participate. Most respondents worked for a local or State transportation agency within the United States, with a few exceptions.

The survey questions were formulated based on the study objectives and RQs. The survey included six questions aligned with the study RQs shown in Table 6.

Table 6 Aligning the study research questions (RQs) with the survey questions.

Research question	Survey question
RQ1	How do you and your organization define equity in shared micromobility projects or programs?
RQ2	How do you measure equitability in shared micromobility projects or programs? What initiatives are you or your company taking to ensure that your shared micromobility projects or programs are in line with your vision of equity? How do you/your organization involve the communities you serve in your planning process? What challenges have you faced in implementing equitable shared micromobility projects or programs?
RQ3	Are there any significant successes you've had in promoting equity within your shared micromobility projects or programs? Please explain What challenges have you faced in implementing equitable shared micromobility projects or programs?

Additionally, participants were asked to provide demographic information, including minority identity, experience in the transportation field, experience working with micromobility, contact information, and what organization they currently worked for. Survey responses were qualitatively coded to find the most common responses or themes to each question. Common responses or themes were used to address the study RQs.

4.3. Results

4.3.1. Demographic Information about Participants

In total, 35 transportation professionals participated in the online survey. Of these 35 individuals, 30 were from DOTs, RPOs, or local governments, 3 were from NGOs, and 2 were from the private sector. Qualitative analysis of the survey responses revealed salient findings for each of the survey questions related to equity definition (RQ1), common programs and practices for evaluating equity (RQ2), and common challenges and successes in promoting equity (RQ3). These findings are described below.

4.3.2. Defining Equity in Micromobility (RQ1)

For the equity definition question, about half of responders (48.5%) either did not provide a definition or repurposed a broader definition from the federal government (such as Executive Order 13985) or other local departments. In the responses that included a definition or factors of equity, access was the most commonly identified factor across multiple areas (i.e., availability of vehicles, disability access, affordability, access to decision-making, language access, etc.), with 45.7% of responses including it as a component of equity.

The next most common equity element was equality across demographics, with about a quarter of responses (22.8%) including it. Many responses indicated this as being something akin to equality of opportunity and focusing on raising communities that have been historically disadvantaged. Other identified components also included safety (14.2%), mobility choices (for special transportation needs, or those who rely on alternative transportation; 8.6%), mitigating negative impacts (5.7%), and community engagement (i.e., ensuring that proposed projects include the community in the planning process, and are providing appreciable benefits to the community; 5.7%).

4.3.3. Common Programs and Practices for Equity in Shared Micromobility (RQ2)

Survey questions related to RQ2, as indicated in Table 6, focused on metrics for evaluating equity, practices for fostering equity, and community engagement strategies. The results for each of these three sub-foci are presented below.

Metrics

Related to evaluating equity, about a third of responses (34.3%) indicated that they did not have any reliable metrics. About 28.6% use the percentage of service used in or distributed to equity focus areas (areas identified as disadvantaged or of particular interest in equity discussions) as a metric for whether the service is being distributed equitably. Many local governments partnering with shared micromobility services use distribution requirements as part of their partnership agreements. Nearly a quarter of responders (22.9%) use adoption rates across various socioeconomic demographics to measure if the service is being used equitably. Additionally, 14.3% track the use of assistance programs (lowered fare, technology access, etc.) as part of their equity evaluations. Both the project's impact on equity demographics and community engagement strategies are used by 11.4% of respondents each. Other metrics include accessibility (11.4%), safety (8.6%), affordability (8.6%), and usability (5.7%).

Practices

Of the respondents, 42.9% lacked current practices used to ensure equitability. Meanwhile, 14.3% use various community engagement strategies to promote equity. Additionally, 22.9% either incentivize or mandate service providers to focus on equity or have equity-related assistance programs. Equity evaluations at multiple project stages are used by 8.6% of respondents, while another 8.6% employ equity-focused planning strategies. Similarly, 8.6% allocate funding specifically for equity programs. Diversity in the planning process, ensuring diverse voices are heard, is utilized by 5.7% of respondents. Only 2.9% require service vendors to provide accessible vehicles for disabled users, and another 2.9% use distribution requirements for service vendors to ensure equity.

Community engagement strategies

About half of respondents (45.7%), said they used either workshops or public meetings as a way to engage with the public. Only 22.9% did not explain their strategies for community engagement. Community partnerships, often with non-profits, were used by 20% of respondents. Surveys were employed by 14.3% of respondents to gather community information, while focus groups were used by 11.4% to collect feedback. Stakeholder committees, including community stakeholders, were utilized by 11.4% of respondents. Social media was used by 8.6% of respondents to inform and engage with the community, and interviews were conducted by 5.7%.

4.3.4. Common Challenges and Successes (RQ3)

Challenges

Forty percent of the respondents did not identify any significant challenges in their projects or programs. Among those who did, 22.9% identified symptoms of a lack of centralization as major barriers to implementing equitability, such as a lack of accountability for service providers, instability in the industry, lack of a tracking system or database to use for planning new projects, lack of clarity or consistency of the rules and regulations, lack of consistency in priorities between leadership, and equity programs not being classified as equity-focused, among others. Funding and time constraints were significant for 20% of respondents, often due to a preference for car-focused projects, such as electric vehicle charging stations, or overextended resources like community partners (because of a lack of funding). Difficulties in community engagement were noted by 14.3% of respondents, and 11.4% highlighted the lack of safe, quality infrastructure as an issue. Profit focus, identified by 8.6% of respondents, was a barrier usually because the service vendors were not concerned with equity and governments did not want to invest in new projects. About 8.6% of respondents said regulatory requirements, like insurance and parking minimums, usually put in place because of stigma against micromobility, were a significant barrier to implementing equitable services. Other challenges included stigma or bias against micromobility (8.6%), user behavior (2.9%), maintenance and operation costs (5.7%), and safety risks (2.9%).

Successes

More than half of respondents (54.3%) did not report any significant successes. Among those who did, 17.1% highlighted their affordability program as their most significant success. Increased community participation in the planning process was noted by 11.4% of respondents, while 8.6% reported success with education and outreach programs. Equity-focused policy changes resulting from activism were achieved by 5.7%, and another 5.7% used funding allocations (grants for

nonprofits, or funding directly for engaging communities) to promote equity. One respondent indicated they had increased ridership by using more diversity and representation in marketing materials.

4.4. Discussion

From the results of RQ1, we can see that nearly half the respondents did not have a specific definition for equity in regard to micromobility, even if they had an active transportation program or supervised shared micromobility services. But, much more commonly, they had no hand in these services at all, which accounted for a majority of the “N/A” responses across all questions. It is also important to note that answers could be categorized as including equity factors and also marked as N/A. For example, one response explicitly stated their organization does not have a specific definition of equity, but also provided a “working definition” their division was using in the meantime. For the purposes of this study, “N/A” simply means either the respondent did not provide an answer to the question or the organization the respondent worked for did not have any official answer to the question, regardless of whether the respondent had a different response personally. Synthesizing the identified equity factors, it seems that equitably shared micro mobility systems are those that are accessible (including affordable and easy to use) across all demographics, safe to use, offer a variety of options to meet user needs and mitigate negative impacts on communities by engaging users in the planning process. Notably, current industry practices lack many of these factors, as seen in the results of the challenges question.

In the results of the metrics question, almost none of the respondents gave a clear explanation of their evaluation process, and more than a third (34.3%) indicated they did not have any reliable way of measuring equitability. Most metrics were also focused on quantitative measurements, rather than qualitative, which can lead to issues with biased and unrepresentative data (Sanguinetti & Alston-Stepnitz, 2023). Only 11.4% of the responses indicated they used community feedback as a measurement of the equitability of the service, despite this being one of the most reliable ways to determine how a community perceives a project. Even among the respondents who did identify metrics used in their process, they did not elaborate on how these metrics factored into their process or equity in general. This poses challenges in determining what the best metrics to use in determining equitability are or making recommendations on how to modify the evaluation process going forward.

The responses to the question of the current practice (addressing RQ2) appeared to be more cohesive than arriving at a definition. Most use methods that seem reliable, such as community engagement, evaluations at multiple points during the project, and centering equity in the planning process. However, there is one discrepancy between the responses to this question and the metrics question that indicates current practices do not align with typical ideas of equitability. The most common metric mentioned by the respondents was the percentage of a fleet or service that was distributed to or used in certain disadvantaged areas. Yet, in response to the question of the current practice, only one respondent said they use distribution requirements for their vendors to ensure equitable distribution. This shows that current practices and regulations from governmental organizations are not meeting up with their own self-identified measures of equitability. Although distribution requirements have been noted to fall short of an effective solution to inequity (Hong et al., 2022), if equitable distribution is one of the most important factors for determining equitability, why are more regulatory bodies not using these requirements to ensure that services

are equitable? The conclusion to be drawn here is that many local governments simply do not play enough of a role in regulating these services for them to be able to mandate distribution requirements.

For the survey question regarding community engagement strategies, the most common response was that respondents use public meetings and workshops to gather feedback from the community. The primary purpose of this question was to gauge whether respondents actually involved communities in their process and whether they knew enough about the process to give details on how these people were involved. Thus, the specific method for engagement does not have much effect on the results of the study. However, a recommendation for moving forward could be to utilize social media more frequently, as this could be a better way to involve young people and those who do not have the time or means to participate in public meetings.

The challenges question (addressing RQ3) produced some very interesting and actionable responses. The most common challenges identified were direct results of a lack of centralization or oversight in industry. This includes a lack of accountability for service providers, who are mainly profit-driven and not concerned with equity at all unless mandated. It also includes the lack of a management tool or tracking system to identify where projects should be implemented or even to track safety statistics like crashes, as well as the lack of clarity and consistency in definitions, rules, and regulations, and the instability of the industry, leading to a constantly changing market and leadership with constantly changing priorities. The lack of funding for micromobility or equity projects also poses a major barrier. Many of those seeking to create a more equitable system rely heavily on community partners and nonprofits to plan projects, gather feedback, and inform the community of the service but are unable to work closely with these partners because of very limited resources and a high turnover rate, which could be significantly improved by increased funding. In addition, respondents stated many cities would rather invest in more subsidies and infrastructure for cars, such as building new electric vehicle (EV) charging stations, rather than taking on the perceived risk of building or maintaining infrastructure for micromobility or bikes. As one respondent put it, we cannot hope to have an equitable micromobility industry until we have a more equitable allocation of infrastructure and funding. This directly ties to the responses which cited a lack of infrastructure as a major barrier.

As for the question of success, there were not many significant results to speak of. Over half (54.3%) of respondents did not have any significant success contributing. Most of the ones who did point to their affordability program, though this is a very small-scale solution to one specific problem. This could be because affordability programs (i.e. discounted fare options) are relatively simple to implement and do not require specialization based on the location. The policy change achieved was either not specified, or a result of activism taken on by the respondent individually.

Based on the data collected so far, the regulatory side of the shared micromobility industry still has significant progress to make before micromobility services can truly be called equitable. Governmental organizations take a very hands-off approach to regulation and equity, and based on how common it was for respondents to say their organization had no part in operating these systems, or give extremely non-specific answers, it seems that many simply do not know much about these services. It has been 7 years since shared micromobility has become a significant transportation market, and many of these organizations still do not have an official definition of

equity, no reliable metrics for evaluating equitability, or any plan for implementing these services. Shared micromobility is essentially a self-regulating industry and suffers from a lack of consistency or clarity in almost every aspect of its operation. In order for these services to become equitable, there are two paradigm shifts that must occur. Firstly, government bodies must shift attention away from ever-increasing funding and resource allocation for cars and start investing in alternative modes of transportation. Secondly, shared micromobility services must come under the supervision of centralized regulatory bodies (such as DOTs or a coalition of smaller transit agencies) in order to clarify and solidify the operation of these services.

While it appears that collaboration between municipalities is necessary to standardize the operation of equitable micromobility services, the best method to achieve this is still unclear. The reason for the lack of any notable successes in the industry is also unclear, though it is likely due to the number of barriers organizations encounter when attempting to implement these services. It is also unclear how this industry currently operates, as it seems not many localities are directly involved in the regulation or implementation of these services, and in researching private service vendors, it is difficult to find the teams who are otherwise responsible for this. Future research will continue to investigate how transportation professionals and vendors conceptualize and implement equitable shared micromobility services through additional surveys and reviews of transportation masterplans.

4.5. Summary of Findings and Recommendations

The shared micromobility industry – proposed as a solution to many transportation issues – suffers from a lack of oversight and consistency in regulation. Many find these services to be prohibitively expensive, and regulations on usage combined with a lack of infrastructure prevent users from finding an appropriate location to use these devices. In order to discover how transportation authorities currently approached regulating these services, a survey was given to transportation officials mainly across the U.S. The results indicate that many organizations do not have a clear definition of equity, or strategy for ensuring systems are equitable, and current practices leave a majority of the work in the hands of private vendors. Respondents also identified a plethora of barriers to implementing these services, especially to implementing them equitably, and not many successful solutions to these barriers.

The study findings seem to indicate that the shared micromobility industry is largely self-regulated, and transportation authorities take a hands-off approach to the implementation of these services. In order to improve equity outcomes, it is necessary for these authorities to invest more in alternative modes of transit and work together to create a solidified standard of regulation and process for implementation. Future research should focus on identifying the best ways for municipalities to coordinate micromobility services and the key individuals responsible for planning and implementation.

5. CONCLUSIONS

This report examined shared micromobility as an alternative transportation option, exploring its opportunities and challenges in mid-sized U.S. cities and small towns. It is structured into three chapters. The first chapter analyzed micromobility usage patterns, using Tacoma as a case study to identify trends, key influencing factors, and user demographics from an equity perspective. The second chapter investigated the factors contributing to micromobility crashes, examining how these factors cluster and their relationship to types of body injuries. The last chapter highlighted the need for equity standards in shared micromobility, drawing on insights from interviews with transportation professionals, including representatives from DOTs, RPOs, local governments, NGOs, and the private sector.

Micromobility usage in Tacoma was examined using a BQR model with Razor micromobility data to identify key factors influencing ridership. The analysis highlights disparities in usage based on race, gender, income, and infrastructure access. Shared micromobility is more commonly used in high-trip-rate areas with better bike lane availability, pedestrian and bike trails, and transit access but poorer pavement conditions. Lower vehicle ownership correlates with higher micromobility use, while middle-income groups are less likely to adopt it, possibly due to car dependency. Terrain and environmental factors also play a role, with moderate slopes and increased tree coverage associated with higher usage. High-trip-rate areas have more open space and residential land but less commercial land, suggesting the need for micromobility hubs near transit stations and commercial zones. The findings suggest that to improve micromobility in mid-sized cities, equity-focused strategies should be implemented to enhance access in minority and low-income communities. Infrastructure investments, such as expanding bike lanes, pedestrian pathways, and transit connections, are essential for improving accessibility in underserved areas. Introducing pricing and affordability programs, including subsidies or tiered pricing structures, can make micromobility more accessible to low-income users. Efforts to encourage female ridership should address safety concerns by increasing lighting and ensuring the equitable placement of micromobility devices during the rebalancing process. Additionally, targeted expansion in high-demand areas with strong transit connections and high residential density can optimize service efficiency. Beyond urban areas, exploring the potential for micromobility expansion in rural communities could improve first- and last-mile connectivity, providing residents with greater access to essential services and employment opportunities. By addressing these factors, mid-sized cities can promote micromobility adoption, improve equity, and support sustainable urban mobility.

Safety is also a reason that can make people refrain from using micromobility devices. The analysis of micromobility crash data in Washington using the CCA approach revealed three clusters with distinct patterns and contributing factors. The first cluster represents crashes that occur on roadways or sidewalks, with micromobility users often over 30 years old, particularly women, sustaining minor or no injuries. These crashes frequently involve distracted or improperly maneuvering vehicle drivers. The presence of micromobility users on shoulders or sidewalks, along with non-junction locations and uncontrolled intersections, also contributes to these incidents. The second cluster involves crashes at intersections controlled by signals or stop signs, with a focus on older male drivers (65+), who often fail to yield to micromobility users. These crashes are characterized by micromobility users riding in the same direction as traffic on bike routes and suffering orthopedic injuries. The third cluster focuses on crashes that occur at

crosswalks within intersections, often involving younger micromobility users (under 30), who fail to yield the right-of-way and disregard traffic signs or signals. These crashes typically involve vehicle drivers traveling straight, and the micromobility users may be exceeding safe speeds. Behavioral factors like disregarding traffic rules and speeding are identified as key contributors to crash severity. Based on the findings, several recommendations could be made to improve micromobility safety. First, cities should invest in infrastructure that separates micromobility users from vehicle traffic, such as dedicated bike lanes and paths, especially in areas where high-risk crashes occur. For older drivers, targeted education and awareness programs are needed, particularly regarding yielding to micromobility users. In addition, promoting safe riding behaviors, such as obeying traffic rules and adhering to speed limits, should be a priority for younger riders. Improving intersection designs, particularly in areas with high pedestrian and micromobility traffic, can also reduce crash risk. Finally, enhancing road maintenance and managing speed, especially in wet conditions, will contribute to safer micromobility use overall.

The shared micromobility sector, which is often promoted as a solution to various transportation challenges, faces significant issues due to inconsistent regulation and a lack of oversight. The analysis of opinions from transportation professionals reveals that micromobility services are too expensive, and the absence of proper infrastructure, combined with unclear usage regulations, makes it difficult for users to find suitable locations to operate these devices. To better understand how transportation authorities are currently addressing these challenges, a survey was conducted among transportation officials, primarily in the U.S. The results revealed that many organizations lack a clear definition of equity or strategies to ensure equitable access to these services, leaving much of the responsibility to private vendors. Respondents also identified numerous barriers to implementing these services equitably, with few successful solutions to overcome these obstacles. The findings suggest that the shared micromobility industry largely operates without sufficient regulation, with transportation authorities taking a passive role in its implementation. To achieve better equity outcomes, it is essential for transportation authorities to make greater investments in alternative transit options and collaborate on establishing a unified regulatory framework and implementation process. Further research should explore effective methods for municipalities to coordinate micromobility services and identify the key individuals involved in planning and execution.

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