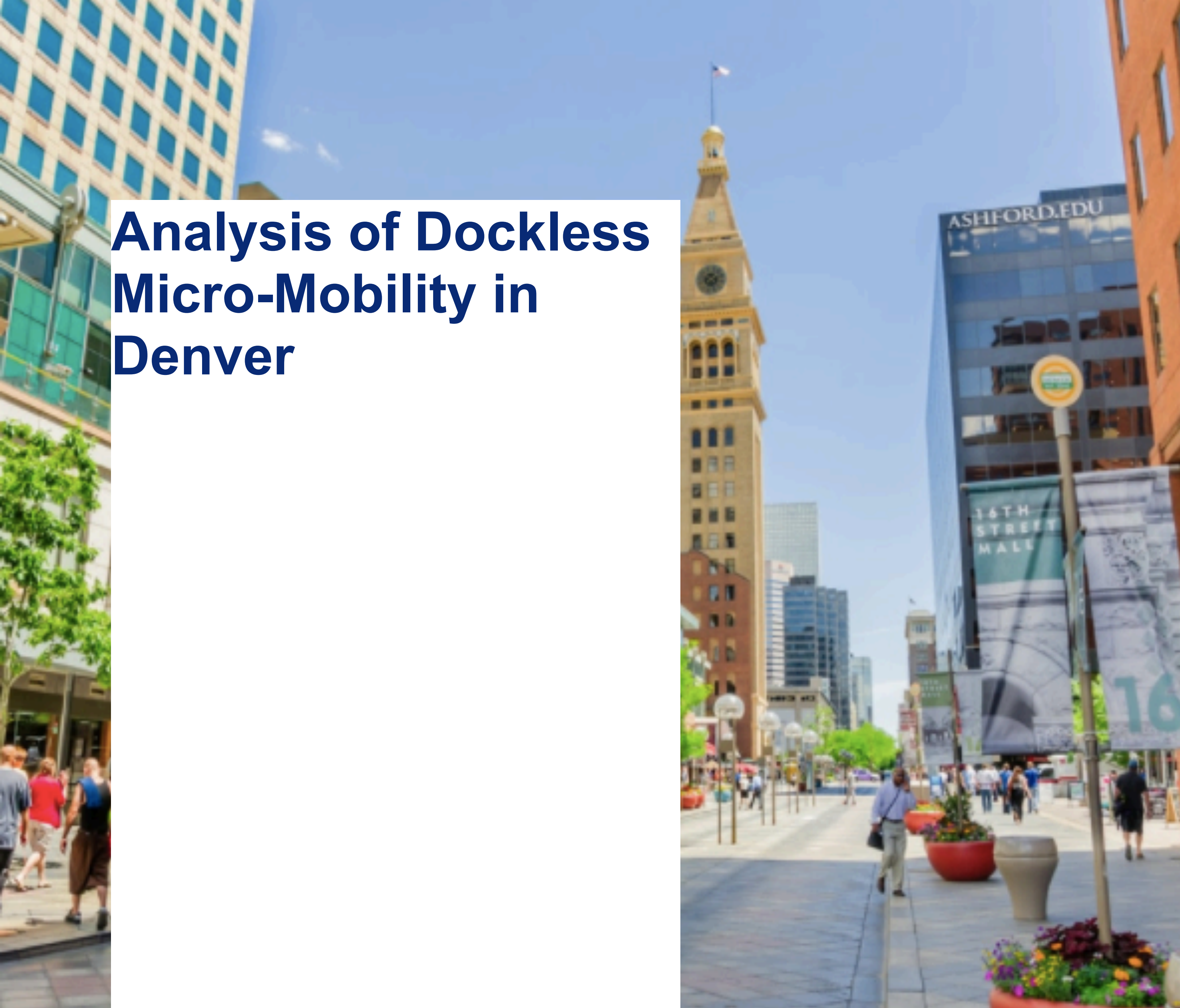


# Analysis of Dockless Micro-Mobility in Denver

[MAY 2020]

**Prepared by CU Denver for the City of Denver**

**Authored By: Samuel Blake, Chad Ellertson, Elly Evans, Zachary Johnson & Robert Lavie**

COLLEGE OF LIBERAL ARTS AND SCIENCES
Geography and Environmental Sciences
UNIVERSITY OF COLORADO DENVER

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# Introduction

## Micro-mobility in Denver

Over the past several decades, Denver has seen a significant increase in population. This growth has been beneficial, encouraging a strong housing and job market and overall economic prosperity. However, Denver's growth in a relatively short period of time has put stress on its transportation infrastructure, with traffic congestion and long travel times being a common commuter complaint. One strategy to address this is to diversify transportation infrastructure to ensure commuters have multiple mobility options. A multimodal transportation system – one which supports public transportation, pedestrians, bicycles, and other micro-mobility options – can help to ease traffic congestion, promote greater equity, support public health and safety, and contribute to urban sustainability and climate resilience[1].

Until recently, primary modes of transportation in Denver included automobiles, public transit, biking, and walking. The introduction of dockless electric mobility vehicles by companies like Uber, Lyft, and Lime, forced the city to reevaluate the place of scooters within its transportation system. Once considered "toy vehicles," and only allowed to be operated on sidewalks, a 2019 ordinance declared dockless electric scooters "electric mobility scooters," prohibiting their use on sidewalks and permitting their operation in bike lanes and roads[2]. Public opinion regarding electric scooters (e-scooters) has been mixed. Some residents see them as a nuisance, as well as a threat to public safety, while others see them as an important new technology that may play a vital role in the future of urban mobility.

Despite the controversy and difficulty of managing e-scooters in Denver, they remain popular. Ultimately, these novel micro-mobility technologies may have the capacity to fill an integral gap in transit systems by offering an easy and convenient way for commuters and tourists to move throughout urban areas without the use of a personal automobile. As micro-mobility technologies like e-scooters and dockless electric bikes become increasingly popular, it is important to consider how current infrastructure supports micro-mobility, and how they might be managed appropriately to increase transportation equity and sustainability. This study is concerned primarily with literature and analysis that examines how micro-mobility technologies may contribute to more equitable transportation infrastructure.

[1] Litman, T. (2007). Evaluating rail transit benefits: A comment. Transport Policy, 14(1), 94-97. doi:10.1016/j.tranpol.2006.09.003
[2] City of Denver city ordinance 14-1876

# Problem Statement & Report Goals

The City of Denver is concerned with the accessibility, equity, safety, and sustainability of its transportation infrastructure. This report investigates micro-mobility vehicles in Denver through the lens of equity and infrastructure, analyzing the potential of this mode of transportation to reach the city's transportation goals. It is concerned with the role of micro-mobility vehicles in Denver's transportation infrastructure. Specifically, our working group will:

1. Address how micro-mobility vehicles may or may not help Denver meet overall transportation goals
2. Analyze how current infrastructure does or does not support safe micro-mobility vehicle use
3. Address how micro-mobility vehicles may play a role in addressing transportation equity concerns
4. Identify ideal locations for dockless vehicle parking or charging stations in equity areas that will promote diverse and equitable access

# Report Goal 1:

## Address how micro-mobility vehicles may or may not help Denver meet overall transportation goals

### Micro-mobility Trends

Throughout the United States, alternative forms of mobility are helping to steer urban commuters away from their dependence on single-occupancy vehicles and towards more sustainable alternative forms of transportation. Bicycles have long existed in urban landscapes and have slowly been increasing in popularity. Public transportation has been a mainstay in most large cities and offers commuters respite from long travel times and traffic congestion. New micro-mobility technologies are quickly growing in popularity and becoming an increasingly common sight in cities across the country. These services provide a quick and convenient form of transportation using an app-based approach, where residents of a city may use the service and incur charges based on the distance traveled in addition to an initial service fee.

Electric scooters and bicycles are the two primary modes of micro-mobility. In Denver, there are five electric scooter companies – Lime, Bird, Lyft, Razor, and Spin - and two electric bike companies – Jump and Lyft. Run by private operators, micro-mobility companies negotiate contracts with cities to engage in for-profit deployment of their services. For e-scooters, companies compensate nearby residents for the collection, charging, and distribution of their vehicles, while e-bikes are generally managed directly by the proprietor. The novelty surrounding these services is apparent as many city dwellers use these vehicles for recreation, as well as fast and convenient commuting. However, even with the appeal of electric scooters, shared bicycles remain the most common form of micro-mobility travel in cities[3].

In recent years, micro-mobility companies have rolled-out electric scooters and bicycles in numerous cities[4]. These cities have subsequently responded with varying degrees of acceptance, ranging from generous incentives to outright bans[5]. Current literature indicates that there is no single policy for cities to engage in which ensures micro-mobility meets their specific needs. In part, this is due to micro-mobility operators establishing services in cities of various sizes and geographic patterns. While there are certainly active programs in large cities like New York, Los Angeles, and Washington D.C., programs

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[3] Dupuis, N., Griess, J., & Klein, C. (2019). Micro-mobility in Cities: A History and Policy Overview. National League of Cities.

[4] Bordenkircher, B., & O'Neil, R. L. (2018). Dockless bikes: Regulation breakdown. Chicago: Twelve Tone Consulting

[5] Wood, J., Bradley, S., & Hamidi, S. (2019). *Preparing for Progress: Establishing Guidelines for the Regulation, Safe Integration, and Equitable Usage of Dockless Electric Scooters in American Cities.*

also exist in smaller and more suburban areas like Scottsdale, AZ[6]. As of May 2019, there were 81 different US cities with active e-scooter programs[6]. With such variation, a uniform set of policies and regulations has yet to emerge which easily adapts to fit every municipality's needs. The lack of common best practice policies has resulted in a patchwork of regulations and ordinances related to micro-mobility across the nation[6].

Spatial variation notwithstanding, there are certain measures which all cities can engage in to ensure a mutually beneficial relationship with micro-mobility operators and their riders. Principally, micro-mobility companies need to provide cities with full access to ridership data, and cities need to implement the data into immediate transportation plans[6]. Simply providing the data is not enough, as it needs to be actively implemented in short and long-term planning to ensure sufficient rates of micro-mobility use. Micro-mobility companies generally have the resources to analyze this data independently, which enables them to make proactive decisions in their best interest, while government officials are forced to make reactive decisions. Additionally, agreements need to place some level of responsibility on micro-mobility companies for maintaining the quality and equitable deployment of their fleet[7]. Public outreach and education are also often necessary to encourage marginalized populations to utilize micro-mobility solutions. The onus to run a public outreach program ought to be the responsibility of the company[8]. Engaging in a constructive partnership is the best way to accomplish these goals, making micro-mobility a more accessible and reliable transportation solution.

## Denver's Infrastructure

Denver's recent population boom has initiated a significant shift in the city's transportation infrastructure. From 2017 to 2018, Denver welcomed 44,188 new residents equating to a population increase of 1.53%, making Denver the 19th largest metropolitan region in the United States[9]. Additionally, Denver is an active participant in transit-oriented development which focuses on accessibility and encouraging the use of existing transit systems[10]. Implicitly, Denver's emphasis on public transportation is due to relatively consistent population growth since the 1950's.

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[6] Wood, J., Bradley, S., & Hamidi, S. (2019). *Preparing for Progress: Establishing Guidelines for the Regulation, Safe Integration, and Equitable Usage of Dockless Electric Scooters in American Cities.*

[7] Shaheen, S., & Cohen, A. (2019). Shared Micromoblity Policy Toolkit: Docked and Dockless Bike and Scooter Sharing.

[8] Douma, F., & Hauf, A. (2018). Governing Dockless Bike Share: Early Lessons for Nice Ride Minnesota.

[9] New Census data: See how Denver's population growth compares to other large metros. (2019, April 20). US Official News. Retrieved from https://link-gale com.aurarialibrary.idm.oclc.org/apps/doc/A583117691/STND?u=auraria_main&sid=STND&xid=55adee68

[10] Ratner, K. A., & Goetz, A. R. (2013). The reshaping of land use and urban form in denver through transit-oriented development. *Cities, 30*, 31-46. doi:10.1016/j.cities.2012.08.007

Denver's transit system officially started in 1969, operating under the Regional Transportation District (RTD), with the purpose of providing regional transportation services to the Denver metropolitan area[11]. Governed by a board of directors, members of the board are publicly voted in and represent one of the 15 districts it serves. Today, RTD supports mobility in eight Front Range counties around Denver and serves approximately 3.08 million potential passengers[12]. The total area supplied by RTD services constitutes approximately 2,342 square miles while currently operating with the following services:

| Bus Routes | Rail Lines |
|---|---|
| 124 Local | 8 light rails |
| 16 Express | 3 commuter rails |
| 16 Regional | |
| 16 Limited | |
| 8 SkyRide | |

Currently, the City of Denver acknowledges inefficiencies regarding transportation, including a high volume of single-occupancy commuter vehicles and a deteriorating infrastructure which no longer supports the volume of traffic. Moving towards a solution, the City of Denver has introduced a Mobility Action Plan (MAP)[13]. This plan is targeted at introducing modes of transportation with public appeal, while also contributing to the safety of passengers. The plan was designed, in part, due to the high volume of traffic during commuting times, along with limited mobility options for many Denver residents.

The MAP was designed with the intention of public transit transformation as Denver understands the necessary changes which must be made to mobility options in the city. The plan takes into consideration increasing available mobility options, promoting safety, reducing carbon emissions, supporting public health, and promoting accessibility of mobility options. The following goals are outlined in Denver's MAP[13]:

- Reduce single-occupant vehicle (SOV) commuters from 73% to 50% by 2030
- Zero traffic-related fatalities by 2030 though a Vision Zero campaign
- Reduce greenhouse gas emissions in Denver by 2050
- An accessible and reliable multi-modal network which is available to everyone
- Organizing and planning the MAP around public opinion

[11] Regional Transportation District. (2019). 2019 Factsheet Booklet. Retrieved on February 24, 2020.
[12] Regional Transportation District. (2019) Facts & Figures. Retrieved February 24, 2020.
[13] City of Denver. (2017). Denver's Mobility Action Plan. Retrieved from https://www.denvergov.org/content/denvergov/en/mayors-office/programs-initiatives/mobility-action-plan.html

## Micro-mobility in Denver

The City of Denver's MAP mobility goals highlight the importance of choice, safety, climate, health, and accessibility. As micro-mobility options grow increasingly popular, it is important to consider their role in the current transportation infrastructure system and how they might be useful or detrimental in reaching these overarching mobility goals. Authors in one review of micro-mobility argue that e-scooters and other micro-mobility options may lead to, "increased mobility, reduced greenhouse gas emissions, decreased automobile use, economic development, and health benefits."[14] While studies such as these are encouraging, one must consider micro-mobility in a local context and explore how these dockless vehicles might help Denver achieve their overall goals.

### *Choice*

A diverse transportation system focused on alternative non-car options can lead to a decrease in trips made by single-occupancy vehicles[15]. E-scooters may fill a vital role as a "last mile" transportation option, offering public transit users a way to get from their front door to a bus or train stop[16]. In their 2020 study, Gössling discusses e-scooters from a public opinion perspective, examining why residents may or may not choose to ride an e-scooter. Safety, space, and general irresponsible behavior (riding, cluttering, vandalism) were cited as primary concerns[17]. By addressing these concerns – for example by enforcing speed limits, ensuring there is adequate road space dedicated to scooters, bikes, and pedestrians, or through public education and safety campaigns – e-scooters could become a viable and important transportation option for Denver residents.

### *Safety*

Safety is consistently expressed as a concern in cities with micro-mobility vehicles[18]. Pedestrians often feel unsafe around e-scooters, and, both e-scooters and dockless bikes are often parked on sidewalks in the pedestrian right of way creating unsafe conditions particularly for elderly or differently abled individuals[19]. These are legitimate concerns, but also might be easily addressed through policy and regulation, for example by enforcing speed limits, geofencing deployment zones, designating e-scooter

[14] Shaheen, S., & Cohen, A. (2019). Shared Micromoblity Policy Toolkit: Docked and Dockless Bike and Scooter Sharing.
[15] Lee, R. J., Sener, I. N., & Jones, S. N. (2017). Understanding the role of equity in active transportation planning in the united states. *Transport Reviews, 37*(2), 211-226. doi:10.1080/01441647.2016.1239660
[16] McKenzie, G. (2019). Spatiotemporal comparative analysis of scooter-share and bike-share usage patterns in washington, D.C. *Journal of Transport Geography, 78*, 19-28. doi:10.1016/j.jtrangeo.2019.05.007
[17] Gössling, S. (2020). Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change. Transportation Research Part D: Transport and Environment, 79, 102230.
[18] James, O., Swiderski, J. I., Hicks, J., Teoman, D., & Buehler, R. (2019). Pedestrians and E-Scooters: An Initial Look at E-Scooter Parking and Perceptions by Riders and Non-Riders. Sustainability, 11(20), 5591.
**[19]** Gössling, S. (2020). Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change. Transportation Research Part D: Transport and Environment, 79, 102230.

and dockless bike parking zones throughout the city, and prohibiting riding on sidewalks[19]. Despite the potential safety issues caused by micro-mobility vehicles, a diverse transportation system with more road space devoted to micro-mobility options could result in a safer environment overall. A bicycle safety study found that cities with more bike infrastructure had a lower rate of road accidents for all road users, not only cyclists[20]. This data suggests that expanding micro-mobility options and infrastructure in Denver could help in achieving the city's "Vision Zero" goal and make the city streets safer for everyone.

### *Climate & Health*

E-scooters and bicycles offer a relatively low emission transportation option while having the potential to reduce air pollution and promote positive public health outcomes[21]. Survey results suggest that as many as 34% of car trips could be offset by e-bikes and scooters[22]. Micro-mobility options may also be a vital component as the city works towards its "80 x 50 Climate Goal." However, there are environmental externalities related to e-scooters specifically, which should be considered. The primary environmental impacts of e-scooters are emissions attributed to car miles accrued during redistribution and charging, and the relatively short life span of the scooters themselves due to poor construction and vandalism[23]. By streamlining the redistribution process, installing public charging stations in high use areas, incentivizing a switch from car to bike or scooter for redistribution, and enforcing anti-vandalism laws, the City of Denver can avoid or diminish the impacts of these externalities[24].

### *Accessibility*

Shared micro-mobility options make it easier for city residents to travel through the city, and act as a "last mile" transportation option. Additionally, these services support commuter travel to transit stops (bus, rail, shuttles) increase transit connectivity, and promote spatial equity. If managed appropriately, micro-mobility options could also promote social equity by offering a safe and reliable transportation option to lower income and underserved neighborhoods. Some suggestions to make micro-mobility accessible to all city residents are to provide multiple pay options that do not require a credit card or smartphone, require micro-mobility companies to disperse a certain number of e-scooters and dockless bikes to lower income neighborhoods, and reach out to community leaders to identify strategies to encourage diverse use.

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[20] Marshall, W. E., & Ferenchak, N. N. (2019). Why cities with high bicycling rates are safer for all road users. Journal of Transport & Health, 13, 100539. Rob Van Der Bijl, Oort, N. V., & Bukman, B. (2018). Light rail transit systems: 61 lessons in sustainable urban development. US: Elsevier.

**[21]** Hardt, C., & Bogenberger, K. (2019). Usage of e-scooters in urban environments. Transportation research procedia, 37, 155-162.

**[22]** Hollingsworth, J., Copeland, B., & Johnson, J. X. (2019). Are e-scooters polluters? The environmental impacts of shared dockless electric scooters. Environmental Research Letters, 14(8), 084031.

**[23]** Luo, H., Kou, Z., Zhao, F., & Cai, H. (2019). Comparative life cycle assessment of station-based and dockless bike sharing systems. Resources, Conservation and Recycling, 146, 180-189.

# Report Goal 2:

## Analyze how current infrastructure does or does not support safe micro-mobility vehicle use

Much of the criticism regarding electric scooters in urban environments is related to how different forms of mobility take up space within transportation infrastructure. Electric scooters add another layer of complexity to transport systems as they compete over space with other forms of mobility[25]. Cities often struggle to place electric scooters within a transportation system – do they belong on the sidewalk or in the road? While scooters on the sidewalk pose public health and safety risks to pedestrians, bicyclists and scooter riders also may not feel safe sharing roadways with cars. To mitigate conflict between motorists, bicyclists, scooter riders, and pedestrians, city planners must be mindful of how infrastructure space is allocated.

Unfortunately, a mindful integration of electric scooters into currently existing infrastructure systems is not always possible, as was the case in Denver. In late spring of 2018, scooters appeared on the streets of Denver seemingly overnight. This scooter “dead drop” by the companies Lime and Bird essentially took city officials by surprise, forcing them to enact a set of ad hoc reactive regulations to ensure scooters were not being left in the public right of way or posing a public safety risk. Similar tactics were used in other major cities across the United States. After a brief dockless mobility ban and a readjustment period, Denver city officials allowed e-scooter and bike companies back into the city and passed an ordinance that required electric scooters to use the bike lane when present, road when not, and sidewalk only in cases where the roadway speed limit was over 30 miles per hour.

With electric scooters growing in popularity, it is important to be aware of and address infrastructure gaps, or areas and corridors that are at greater risk of seeing conflicts between cars, bicycles, scooters, and pedestrians. This could include high-speed or high-volume roadways without bike infrastructure where scooter users are forced to share the sidewalk with pedestrians. This could also include higher volume roads with bike infrastructure, where scooters, bicycles, pedestrians, and cars are all competing for space.

[25] Gössling, S. (2020). Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change. Transportation Research Part D: Transport and Environment, 79, 102230.

In order to assess the degree to which Denver's infrastructure does or does not support micro-mobility, our team performed a simple suitability analysis of infrastructure that allows scooter users and city officials to visualize various scales of safety of roadways. Roads that are safer may see higher volumes of scooter traffic. Roads that are more dangerous may see more conflict between scooters, pedestrians, and cars. This analysis may be bolstered or reinforced by observational or survey data as well. While this form of data collection was not possible during the present analysis, our team suggests some tactics and relevant lines of questioning to get a better sense of scooter suitability and user perceptions around Denver's infrastructure.

# Report Goal 3:

## Address how micro-mobility vehicles may play a role in addressing transportation equity concerns

### *Transportation Equity*

Transportation equity is a growing concern among planners and decision-makers in municipalities across the United States. Yet the concept of inclusive ridership is still not widely represented in many transportation planning outcomes[26]. The Transportation Equity Act for the 21st Century (TEA-21) requires all transit agencies that receive federal funding to create and maintain standards for equitable access to public transportation[27]. However, this does not directly apply to most micro-mobility options, as they are funded or operated by private companies and nongovernmental organizations. Subsequently, it is important for city governments to be responsible for ensuring equitable access to new transportation trends.

Transportation equity is not universally defined, but the literature generally agrees that it involves a fair distribution of the costs and benefits of transportation interventions among a population[28]. Active transportation equity can be divided into four different categories: social equity, spatial equity, a combination of social and spatial equity, and procedural equity[15]. Schneider (2019) combines social equity and spatial equity in her work analyzing access to micro-mobility in Los Angeles. This study takes a similar approach with the primary focus on spatial and social equity. However, this study does not include procedural equity although procedural equity is also important as it involves the consideration and representation of underserved groups in the decision-making process.

### *Transportation Deserts*

Despite the listed advantages, city transit systems are often designed retroactively to accommodate population growth and new development. Furthermore, as cities seek to redevelop through gentrification and economic investment, increasing property values commonly push lower income communities toward suburban locations where cheaper property exists[29]. Consequently, transit

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**26** Lee, R. J., Sener, I. N., & Jones, S. N. (2017). Understanding the role of equity in active transportation planning in the united states. *Transport Reviews, 37*(2), 211-226. doi:10.1080/01441647.2016.1239660

**27** Welch, T. F., & Mishra, S. (2013). A measure of equity for public transit connectivity. *Journal of Transport Geography, 33*, 29-41. doi:10.1016/j.jtrangeo.2013.09.007

**28** Schneider, K. (2019). *Wheels for all: Ensuring Equitable Access to Dockless Mobility in Los Angeles*. Los Angeles, CA: The University of California Institute of Transportation Studies.

**29** Allen, D. J. (2018). Lost in the transit desert: Race, transit access, and suburban form. Abingdon, Oxon;New York, NY;: Routledge, an imprint of the Taylor & Francis Group.

stations may not adequately serve all communities equally, particularly those who would benefit the most from public transit systems.

Communities disconnected from public transportation options are known as “transit deserts.” Transit deserts are often characterized by the extended distance from, or lack thereof, mobility services. They may also be present where the transit demand outweighs the transit services supplied[30]. Locating transit deserts relies on the demand for such services, the presence of a transit-dependent population, and the service proximity of current mobility options. Once identified, proper urban planning strategies can provide an effective tool to overcome the issues associated with transit deserts, by creating mobility options for those who currently lack accessibility.

### *Spatial Equity*

Spatial equity involves the built environment, including existing infrastructure, land use, and distance to public transit[31]. The spatial equity approach examines the geographical distribution of access to transportation to determine where inequalities exist[32]. This approach has the potential to analyze where appropriate infrastructure is available for micro-mobility vehicles and if access to such infrastructure is equally distributed. Micro-mobility options are being recognized as a first and last mile solution for getting to and from public transit, so locating “transit deserts” for micro-mobility deployment may have a beneficial impact for underserved neighborhoods[332].

### *Social Equity*

The social equity approach investigates socioeconomic factors that might restrict access to transportation for certain groups. This focuses on historical barriers to transportation such as income, ethnicity, age, and gender[3]. Recent studies on docked bike sharing systems have found that these programs tend to favor socioeconomically advantaged groups while those who stand to benefit the most from such programs usually lack access to them[4]. Micro-mobility programs have the potential to increase equity in shared transportation, because the vehicles are not tethered to docking stations

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**30** Jiao, J. (2017). Identifying transit deserts in major texas cities where the supplies missed the demands. *Journal of Transport and Land use, 10*(1), 529-540. doi:10.5198/jtlu.2017.899

**31** Schneider, K. (2019). *Wheels for all: Ensuring Equitable Access to Dockless Mobility in Los Angeles*. Los Angeles, CA: The University of California Institute of Transportation Studies.

**32** Lee, R. J., Sener, I. N., & Jones, S. N. (2017). Understanding the role of equity in active transportation planning in the united states. *Transport Reviews, 37*(2), 211-226. doi:10.1080/01441647.2016.1239660

**33**Smith, C. S., Oh, J., & Lei, C. (2015). *Exploring the equity dimensions of US bicycle sharing systems*. Kalamazoo, MI: Western Michigan University.

**5** Mooney, S. J., Hosford, K., Howe, B., Yan, A., Winters, M., Bassok, A., et al. (2019). Freedom from the station: Spatial equity in access to dockless bike share. *Journal of Transport Geography, 74*, 91-96.

and they can be deployed by operators to areas where they can benefit underserved groups[5]. A social equity approach is used to determine who will benefit the most from micro-mobility, such as groups that lack access to private automobiles like low income, non-English speaking, and minority groups.

### *Combining Social & Spatial Equity*

To ensure equitable access to micro-mobility transportation, it is critical to incorporate a two-step spatial and social approach. If social equity is ignored, there may be the risk of grouping socioeconomically advantaged neighborhoods with disadvantaged neighborhoods because they both lack access to public transportation[34]. Similarly, discounting a spatial equity approach could risk ignoring historically vulnerable groups living in more prosperous neighborhoods[35]. Therefore, assessing appropriate neighborhoods for equitable micro-mobility deployment should consider both the spatial and social attributes of each neighborhood.

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**34** Lee, R. J., Sener, I. N., & Jones, S. N. (2017). Understanding the role of equity in active transportation planning in the united states. *Transport Reviews, 37*(2), 211-226. doi:10.1080/01441647.2016.1239660

**35** Schneider, K. (2019). *Wheels for all: Ensuring Equitable Access to Dockless Mobility in Los Angeles*. Los Angeles, CA: The University of California Institute of Transportation Studies.

# Report Goal 4:

## Identify ideal locations for docking or charging stations in equity areas that will promote diverse and equitable access

One major issue brought up in discussions about dockless electric mobility vehicles is how and where they are parked when not in use. Concerns about dockless micro-mobility vehicles being parked on sidewalks and in the right of way are consistently expressed in media reports and survey results regarding individual perceptions of e-scooters and e-bikes[36]. Many authors and experts stress that dockless mobility vendors should be held responsible for ensuring that dockless vehicles are parked appropriately and take action to remove any vehicle placed in an unsafe or inappropriate location[37].

Our team agrees that vendor companies should take on any burdens associated with e-bike and e-scooter use, including education on appropriate vehicle use and parking and removal of vehicles parked inappropriately. We also believe that strategically siting dockless mobility vehicle parking across a city might prevent some of the negative externalities associated with their use before it becomes an issue. Strategies range from simple interventions such as painting designated parking areas onto roads or sidewalks, to technologically advanced interventions such as geofencing. Electric geofence boundaries can also be useful in designating "no use" zones for electric scooters.

Strategic parking areas and charging stations might also prevent some infrastructure and emissions-related externalities associated with dockless vehicles. One positive aspect of dockless vehicles pointed out by vendors is that they are a "greener" option, replacing car trips and lowering overall emissions in urban areas[38]. However, several studies on the environmental impacts of scooters refute this point. The primary sources of emissions from e-scooters are associated with their manufacturing and transportation to and from overnight charging stations[39]. One recent study found that in order to have a net positive impact on emissions, dockless vehicles must offset at least 34% of car trips[40]. It is currently unclear what forms of mobility are being displaced in favor of e-scooters and bikes. Initial

[36] James, O., Swiderski, J. I., Hicks, J., Teoman, D., & Buehler, R. (2019). Pedestrians and E-Scooters: An Initial Look at E-Scooter Parking and Perceptions by Riders and Non-Riders. Sustainability, 11(20), 5591.
[37] Bordenkircher, B., & O'Neil, R. L. (2018). Dockless bikes: Regulation breakdown. Chicago: Twelve Tone Consulting.
[38] Lime. (2019). About Lime: Scooter and Bike Sharing Network For Cities and Universities. Retrieved from https://www.li.me/about-us
[39] Hollingsworth, J., Copeland, B., & Johnson, J. X. (2019). Are e-scooters polluters? The environmental impacts of shared dockless electric scooters. Environmental Research Letters, 14(8), 084031.
[40] Luo, H., Kou, Z., Zhao, F., & Cai, H. (2019). Comparative life cycle assessment of station-based and dockless bike sharing systems. Resources, Conservation and Recycling, 146, 180-189.

survey data from Denver suggests that only about 32% of trips were offset by electric scooters, meaning that their presence may be increasing emissions citywide[41].

Our team considers it of utmost importance that dockless vehicles should consistently be deployed to transportation equity areas, or areas of the city where residents have limited access to other transportation options. Dockless mobility vehicles may have the potential to provide much needed transportation options to residents of underserved neighborhoods who currently have limited access to cars or public transit. Some experts suggest that contracts with dockless mobility vendors should stipulate that a certain number of vehicles must be dispersed to equity areas every day[42]. Placing parking areas or charging stations in highly trafficked parts of equity areas may increase the potential for their use.

Simply providing access to micro-mobility vehicles in underserved neighborhoods does not guarantee they will be used or satisfy the needs of the community. One way to further encourage use in equity areas is by reaching out to Community Based Organization (CBO) leaders before deploying micro-mobility vehicles to assess if they are an appropriate solution to the transportation needs of the community[43]. Additionally, cities should take the initiative to monitor micro-mobility user demographics either in house or through third party software and surveys. Acquiring statistically representative data provides insight on micro-mobility adoption rates to determine where deployment initiatives are fair and accessible, as well as locating existing inequalities[44].

In identifying ideal locations for scooter parking areas or charging stations, equity and sustainability is of utmost importance to our team. Siting charging stations in high traffic equity areas might reach the goals of providing consistent transportation options to underserved populations and lowering emissions by reducing the number of car trips associated with dockless vehicles.

**41** City of Denver (2019). Denver Dockless Mobility Program. Retrieved from https://www.denvergov.org/content/dam/denvergov/Portals/705/documents/permits/Denver-dockless-mobility-pilot-update-Feb2019.pdf

**42** Bordenkircher, B., & O'Neil, R. L. (2018). Dockless bikes: Regulation breakdown. Chicago: Twelve Tone Consulting.

**43** Schneider, K. (2019). *Wheels for all: Ensuring Equitable Access to Dockless Mobility in Los Angeles*. Los Angeles, CA: The University of California Institute of Transportation Studies.

**44** Clewlow, R., Foti, F., & Shepard-Ohta, T. (2018). *Measuring equitable access to new mobility: A case study of shared bikes and electric scooters*. Berkeley, CA: Populus.

# Methods & Analysis

## Behavior Observations

Analyzing existing infrastructural data only provides a certain degree of insight into why people utilize micro-mobility devices in the way that they do. While usage behaviors can be determined from data, it would require highly accurate on-board GPS receivers to distinguish whether riders are on the street or the sidewalk in many locations. Due to this consideration, it would be pertinent to observe usage patterns in separate locations around the city to understand how people act.

Initial ideas for analysis focused on generating observational data at geographically distinct areas throughout the city. Observations could focus on whether users utilize micro-mobility devices in accordance with city regulations, as well as determining whether the infrastructure in the area is conducive to appropriate usage. Generating this observational data would allow researchers and city officials to determine whether vehicle usage patterns change in areas based on infrastructure, or if riders factor infrastructure issues into their route.

Results of the infrastructure analysis could identify locations throughout the city where micro-mobility would be considered adequate and inadequate for appropriate usage. A set of four locations (2 adequate and 2 inadequate) could be chosen for staging field observations. Researchers could locate themselves in these areas and observe rider usage patterns, focusing on whether riders utilize the street or the sidewalk. Researchers could engage in observation at peak usage hours (M-F, 11am to 2pm); consistency between observation times would be ideal in establishing a dataset with minimal variation. Analysis could then be conducted on the data to gain better understand of how infrastructure impacts rider behavior. Ideally, observations of ridership behavior would occur during the summer months when people are more likely to utilize micro-mobility as their transportation of choice.

Unfortunately, due to the Stay-at-Home order issued by Colorado Governor Jared Polis on March 26, 2020, collecting observational data was not feasible. Due to shared nature of micro-mobility devices, it is a concern that they may contribute to the spread of the novel coronavirus. Subsequently, ridership is currently at an all-time low, with companies like Bird and Lime opting to remove devices from the city starting March 30, 2020[45]. This unfortunate turn of events renders all observational data generated at this time as uninformative. While people may still be riding the e-scooters currently available, observational data collected during this time would not be representative of typical ridership behavior. For this reason, the observational data generation aspect of this project was indefinitely postponed.

[45] O'Neill, L. 2020. Bird and Lime pull scooters off Denver streets. BusinessDen. https://businessden.com/2020/03/30/bird-and-lime-pull-scooters-off-denver-streets/

# Infrastructure Analysis

***Objective:*** Determine scooter suitability in roadways based on roadway speed limit, road classification, and bicycle infrastructure. Identify regions and/or corridors in Denver that are suitable, moderately suitable, or unsuitable as e-scooter routes. Create visualizations that could provide information to scooter users regarding the best roadways for use, and information to city officials regarding regions or neighborhoods that may need infrastructure improvements to be more suitable.

***Data used:*** Bike infrastructure and street centerlines accessed through Denver GIS data portal. Census data was accessed through the Integrated Public Use Microdata Series[46].

***Approach:*** To determine the suitability of a given roadway for scooter users, our team took into consideration the following variables: roadway speed limit, roadway type, and existing bike infrastructure.

## Roadway Suitability

Denver city ordinance 14-1876 requires scooter users to use bike infrastructure when available. If bike infrastructure is not present and the roadway speed limit is under 30 mph, scooters should use the road. If bike infrastructure is not present and the roadway speed limit is over 30 mph, scooters may ride slowly on sidewalks using extreme caution and giving pedestrians the right of way. Informed by this ordinance, our team considered roadways over 30 mph to be unsuitable, and roadways under 30 mph to be suitable.

In addition to speed limit, our team considered road type in our suitability schema. Highway ramps are often assigned 30 mph, but they are realistically unsuitable for scooters. Additionally, we considered the classification of local, collector and arterial roads, defined by the Federal Highway Administration as follows:

- **Arterial Roads:** A high capacity urban road, arterial roads in an urban context generally connect higher level roads such as interstates, freeways, highways and major arterials to collector and local roads. These roads tend to have higher traffic volumes and more traffic lanes.

[46] Manson, S., Schroeder, J., Van Riper, D., and S. Ruggles. (2019). IPUMS National Historical Geographic Information System: Version 14.0 [Database]. Minneapolis, MN: IPUMS.

- **Collector Roads:** Collector roads generally serve as an intermediary between local roads and arterials, funneling residential traffic to more major roadways.
- **Local Roads:** Local roads are not intended for long distance travel, have generally lower levels of traffic, lower speeds, fewer traffic lanes, and more traffic calming characteristics.

Arterial roads often have speed limits of 30 mph or lower, making them technically legal for scooter riders. However, these roads also tend to have high traffic volumes and little to no space for alternative mobility options such as bikes and scooters. Our team considers arterial roads to be moderately suitable, meaning scooter riders should practice extreme caution. Collector and local roads, which tend to have lower traffic volumes and speed limits, are considered suitable infrastructure by our team.

### Bike Infrastructure Suitability

Our team considers any bike infrastructure to be of the highest order of suitability for scooter use. However, it may be pertinent to consider how different types of bike infrastructure might be either substantively safer or provide the perception of being safer and therefore encourage or discourage scooter use. Our team classified bike infrastructure into 3 levels based on actual/perceived safety levels.

- **Level 1; Off Street Infrastructure:** These are trails and paths designated for non-motorized traffic and shared use. Off street infrastructure provides the safest option for e-scooter users
- **Level 2; Separated Infrastructure:** This includes buffered bike lanes and protected bike lanes. This infrastructure is physically separated from the roadway by painted or physical barriers.
- **Level 3; Signed Infrastructure:** This includes sharrows and simple road signage indicating that bicycles will be present. This type of infrastructure is not physically separated by barriers. While signed infrastructure is better than the absence of bike infrastructure, this type of infrastructure may provide a slightly lower level of safety to e-scooter users.

## Overall Suitability

Using the above criteria, our team established the following set of suitability conditions:

- **Roadways not suitable for micro-mobility:** Roads over 30 mph, highway ramps
- **Roadways moderately suitable for micro-mobility:** Arterial roads (roads that are less than 30 mph but are “through roads” with limited capacity for non-car traffic. These roads are where you are likely to find scooter users opting to use the sidewalk because the road itself is unsafe. Alternatively, suitable roads surrounding these roads may see a higher capacity of scooters and could be focus areas for the city.
- **Roadways suitable for micro-mobility:** All levels of bike infrastructure, local and collector roads with speed limits of 30 mph or less.

## Analysis

***Roadway suitability by census tract:*** ESRI’s “Summarize Within” tool was used through ArcGIS Pro to count the total mileage of road for each classification attribute (Not Suitable, Use Caution, Road OK) per census tract. This tool also generates total percentage of each attribute within census tract. Census tracts were then designated as Road OK, Use Caution, or Not Suitable based on what the highest percentage category existed within the block. Census tracts were also assigned a unique identifying number depending on what bin they were placed in (Road OK – 2, Use Caution – 3, No Scooter – 5).

***Bicycle Infrastructure suitability by census tract:*** Much like the Roadway Suitability analyzed above, Bicycle infrastructure analysis will utilize the “Summarize Within” tool to gain an overall count and percentage of available bicycle infrastructure by census tract. Census tracts were then designated as Road OK, Use Caution, or Not Suitable based on the highest percentage category existing within the block. Census tracts were also assigned a unique identifying number depending on what bin they were placed in (Level 1 – 7, Level 2 – 11, Level 3 – 15).

***Total Suitability:*** Aggregated road and bicycle infrastructure layers were joined to each other using the “Spatial Join” tool in ArcGIS Pro. The unique identifying variables were added together into a new attribute called “total suitability”. The sum value of the unique variables designated how infrastructurally suitable each census tract was for micro-mobility.

## Equity Analysis

***Objective:*** Using socioeconomic and spatial factors, the goal of this work is to define census tracks in the City of Denver which could benefit from improved access to micro-mobility services based on census indicators.

***Data used:*** 2018 Census Data provide by NHGIS IPUMS[47]

***Approach:*** To locate areas needing improved accessibility to micro-mobility services, our team considered socioeconomic and spatial indicators which contribute to micro-mobility service use. Socioeconomic variables signify census tracks which have been historically underrepresented while spatial variables denote tracks which imply impeded accessibility to mobility services. Table 1 outlines the variables used in the equity analysis.

### Selecting Indicators

***Socioeconomic Indicators:*** For this analysis we chose limited English-speaking households, low educational attainment, non-white population, poverty, and unemployment to represent groups most likely to exhibit social and economic barriers to reliable transportation. Previous studies regarding transportation equity agree that low-income and minority groups generally have less access to reliable transportation[48], therefore we chose socioeconomic indicators based on attributes commonly used to represent these groups. For example, the same five socioeconomic indicators were used by Schneider (2019) in her micro-mobility analysis Wheels for All, and four of these indicators are used by the CalEnviroScreen 3.0 Justice Action Plan to identify vulnerable populations disproportionally affected by pollution.

***Spatial Indicators:*** These indicators are chosen to characterize spatial barriers to transportation, and identify areas where residents are most likely to benefit from e-scooter micro-mobility. Our spatial indicators include no vehicle households, walking as transportation to work, public transit as transportation to work, quick commute times, and single-occupancy drivers. Households with no vehicles is the most important indicator for assessing equitable access to transportation as low-income and minority groups tend to have less access to automobiles and therefore have less access to employment and other resources[49]. To identify census tracts where the population finds it difficult to

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[47] Manson, S., Schroeder, J., Van Riper, D., and S. Ruggles. (2019). IPUMS National Historical Geographic Information System: Version 14.0 [Database]. Minneapolis, MN: IPUMS.

[48] Lee, R. J., Sener, I. N., & Jones, S. N. (2017). Understanding the role of equity in active transportation planning in the united states. *Transport Reviews, 37*(2), 211-226. doi:10.1080/01441647.2016.1239660

[49] Schneider, K. (2019). *Wheels for all: Ensuring Equitable Access to Dockless Mobility in Los Angeles*. Los Angeles, CA: The University of California Institute of Transportation Studies.

walk or occupy public transportation as a means of commuting, we inverted the walking as transportation to work and public transit as transportation to work indicators. Inverting these indicators highlights census tracts where the density of these commuters is the lowest, suggesting that existing conditions make it difficult to walk or use public transit. Lastly, we included single-occupancy drivers and short commute times (less than ten minutes) as spatial indicators to provide insight for Denver's Mobility Action Plan goal to reduce single-occupancy drivers.

| Socioeconomic | Spatial |
|---|---|
| Limited English-Speaking Population | Single-Occupancy Commuters |
| Non-White Population | No Vehicle Ownership |
| Low Educational Attainment | Walking as Transportation to Work |
| Ratio of Income to Poverty | Public Transit as Transportation to Work |
| Unemployed Population | Quick Commute Times (Less than 10 mins) |

***Table 1: Spatial & socioeconomic indicators for equity analysis***

## Scoring Indicators

Using a similar approach to Schneider in Wheels for All[50], our team developed an equity scoring index to evaluate census tracks across Denver which have limited accessibility to mobility services. For determining tracks with limited accessibility and equity to transit services, our team considered socioeconomic and spatial factors which influence community ridership of micro-mobility. Although census data does not directly target micro-mobility service use, it does provide a basis for estimating if electric vehicle deployment is accessible across all demographic areas. Additionally, it provides insight on the varying accommodation the current public transit infrastructure has on the Denver communities.

First, the socioeconomic and spatial variables were standardized for area by calculating the density of each indicator per square mile for each census track. Standardizing the data for area reduces the effect of size and creates comparable equity scores for each census tract. Following, percentile rankings calculations were assigned to each density value. Assigning density values a rank allowed for each value to be scored relative to the indicator's distribution. The process to derive percentile ranks was performed in Excel with the Table to Excel geoprocessing tool. Each socioeconomic percentile is consistent in scale, with higher ranks indicating a denser value. The spatial variables are also consistent in this scale, except for "Walking as Transportation to Work" and "Public Transit as Transportation to

[50] Schneider, K. (2019). *Wheels for all: Ensuring Equitable Access to Dockless Mobility in Los Angeles*. Los Angeles, CA: The University of California Institute of Transportation Studies.

Work", as these variables were inverted in their percentile rank. This inversion technique is adopted from Schneider (2019) and suggests census tracks where micro-mobility may be a viable alternative to walking or public transit. High percentile ranks, for these two variables, therefore, indicate areas where the population does not walk or take public transit and other forms of transportation may be of consideration. As we treated all variables, regardless of socioeconomic or spatial contribution, as equally influencing micro-mobility accessibility, we did not assign any weight to the variables. All ranks, therefore, represent their true density percentile rank and contribute equally in this assessment.

The next step consisted of averaging the five equitability indicators across their respective socioeconomic or spatial category. Averaging indicators results in a single rank for each census track across the socioeconomic and spatial percentiles. For example, the Socioeconomic Equity Rank (Average Percentile) for Census Track 08031006813 rank is 78.3% and the Spatial Equity Rank (Average Percentile) is 74.7%.

| **Indicator** | **Density (Sq. Mile)** | **Socioeconomic Percentile Rank** | **Spatial Percentile Rank** |
|---|---|---|---|
| Limited English Speaking | 371.2 | 86.8% | - |
| Non-white populations | 3681.3 | 89.6% | - |
| Low educational attainment | 4215.7 | 81.3% | - |
| Ratio of Income to Poverty | 1584.1 | 71.7% | - |
| Unemployment | 1898.6 | 62% | - |
| Single-Occupancy Commuters | 851.2 | - | 91.7% |
| No Vehicle Ownership | 420.9 | - | 88.9% |
| Walking as Transportation to Work | 30.7 | - | 66.9% |
| Public Transit as Transportation to Work | 383.0 | - | 29% |
| Quick Commute Times (Less than 10 mins) | 813.3 | - | 97.2% |
| **Socioeconomic Equity Rank (Average Percentile)** | - | 78.3% | - |
| **Spatial Equity Rank (Average Percentile)** | - | - | 74.7% |

*Table 2 Percentile rankings for census tract 08031006813*

To ensure all variables equally contribute to the final aggregated equitability ranks, a scaling procedure was performed between the averaged socioeconomic and spatial equity ranks prior to aggregation. Scaling is a procedure which guarantees all variables equally contribute to the final combined equity rank output[51]. Scaling was conducted by dividing each average percentile rank in the socioeconomic and spatial categories by their respective maximum averaged percentile value. The output was multiplied by 10, resulting in scaled socioeconomic and spatial equity rank ranging from 0 to 10. The two scaled ranks were then multiplied together to produce the final combined equity rank. Table 2 illustrates the scaling process.

| | Socioeconomic | Spatial |
|---|---|---|
| Equity Rank (Average Percentile) | 78.3% | 74.4% |
| Scaled Equity Rank | (0.7828÷0.9596) * 10 = **8.16** | (0.7474÷0.7474) * 10 = **10** |
| Combined Equity Rank | 8.16 * 10 = **81.6**<br>The combined equity rank is 81.6 meaning this value is in the 96.5 percentile of the entire combined equity distribution | |

***Table 3 Combined equity rank calculations and combined percentile rankings for census tract 08031006813***

[51] Schneider, K. (2019). *Wheels for all: Ensuring Equitable Access to Dockless Mobility in Los Angeles*. Los Angeles, CA: The University of California Institute of Transportation Studies.

# Results

## Infrastructure Analysis

### Road Infrastructure Suitability

The results of the infrastructure analysis found that the majority of Denver census tracts are dominated by roads that are considered suitable for micro-mobility usage. Of the 2,217.22 miles of Denver road analyzed, 77.48% fell into the “Road OK” category. 8.12% was classified as “Use Caution” while 14.88% was classified as “No Scooters”. The “No Scooter” classification is seen primarily on highways and major roads like Federal and Sheridan. The “Use Caution” category was seen primarily on other major roads with lower speed limits, especially closer to central Downtown Denver, including Colfax, 6th, 20th, and sections of Alameda. The rest of the local roads throughout the city are supportive of micro-mobility vehicles on streets.

| Category | Length (miles) | Percent |
|---|---|---|
| Road OK | 1,949.55 | 77.48% |
| Use Caution | 204.56 | 8.12% |
| No Scooters | 374.48 | 14.88% |
| Total | 2,217.22 | 100% |

***Table 4 Results of road infrastructure suitability analysis***

When this data is aggregated up to the census tract level, it becomes clear that local road infrastructure enables the proper usage of micro-mobility vehicles across the city with 138 tracts being primarily classified as “Road OK”. The only location in the city where road infrastructure may not be quite as conducive to micro-mobility travel is within Denver’s Central Business District (CBD). While roads in this area are all below the 30mph cut-off, the majority of roads in this area are classified as arterial. For these reasons, the census tracts containing Denver’s CBD are classified as “Use Caution”. Micro-mobility vehicle operators in this region may be more likely to ride on the sidewalks as they may perceive the roads to be unsafe.

| Category | Census Tracts |
|---|---|
| Road Ok | 138 |
| Use Caution | 6 |
| No Scooters | 0 |

***Table 5 Results of census tract road aggregation***

## Bicycle Infrastructure Suitability

When considering bicycle infrastructure in this analysis, we identify a different trend. Again, bicycle infrastructure in general is considered always appropriate and safe for micro-mobility users. Census tracts with any form of bicycle infrastructure are going to be better off than census tracts without. Only two census tracts in the southwest section of Denver have no bicycle infrastructure. While all bicycle infrastructure is good, there are still noticeable tiers to bicycle infrastructure with some being conducive to micro-mobility usage while others are not. Of the available 428.96 miles of available bicycle infrastructure, 27.04% was classified as Level 1, 6.69% as Level 2, and 66.27% as Level 3.

| Category | Length (miles) | Percent |
|---|---|---|
| Level 1 (off-street) | 116.0 | 27.04% |
| Level 2 (separated) | 28.66 | 6.68% |
| Level 3 (signed) | 284.31 | 66.27% |
| Total | 428.96 | 100% |

***Table 6 Results of Bicycle Infrastructure Classification***

Aggregation to the census tract reveals certain patterns across the city. Notably, we notice less Level 1 bicycle infrastructure throughout the center of the city. Census tracts with the most inclusive and protected bicycle infrastructure exist along the southeastern portion of the city. There are a few census tracts outside of the CBD and along the i-25 corridor that have adequate bicycle infrastructure.

| Category | Census Tracts |
|---|---|
| Level 1 | 30 |
| Level 2 | 4 |
| Level 3 | 110 |

***Table 7 Results of Census Tract Bicycle Infrastructure Aggregation***

## Overall Infrastructure Suitability

Combining these two datasets speaks to the overall infrastructural suitability of Denver for micro-mobility usage. While majority of the city is dominated by ideal local roads for micro-mobility, there are certainly areas where this is not the case. Bicycle infrastructure could be considered a suitable replacement for less than ideal road conditions, yet Denver's bicycle infrastructure must be increased for this to become a viable option throughout. Areas along the South Platte river trail to the south of the CBD are ideal corridors for micro-mobility usage. These areas are dominated by a high-quality, dedicated trail system and local roads. Areas to the southeast near Cherry Creek Reservoir are in the same category, yet we find more geographical variation with the category of bicycle infrastructure. More recently developed areas to the northeast of the city are also ideal locations for micro-mobility when analyzing available infrastructure.

| Category | Census Tracts |
|---|---|
| Best Road and Level 1 Bike | 26 |
| Best Road and Level 2 Bike | 2 |
| Best Road and Level 3 Bike | 100 |
| Medium Road and Level 1 Bike | 1 |
| Medium Road and Level 3 Bike | 5 |

***Table 8 Results of Road and Bike Infrastructure Suitability Analysis***

The maps on the following page (Figure 1) graphically display the results of the road and bike infrastructure suitability analysis, as well as a combined result of the two analyses, representing total suitability by census tract.

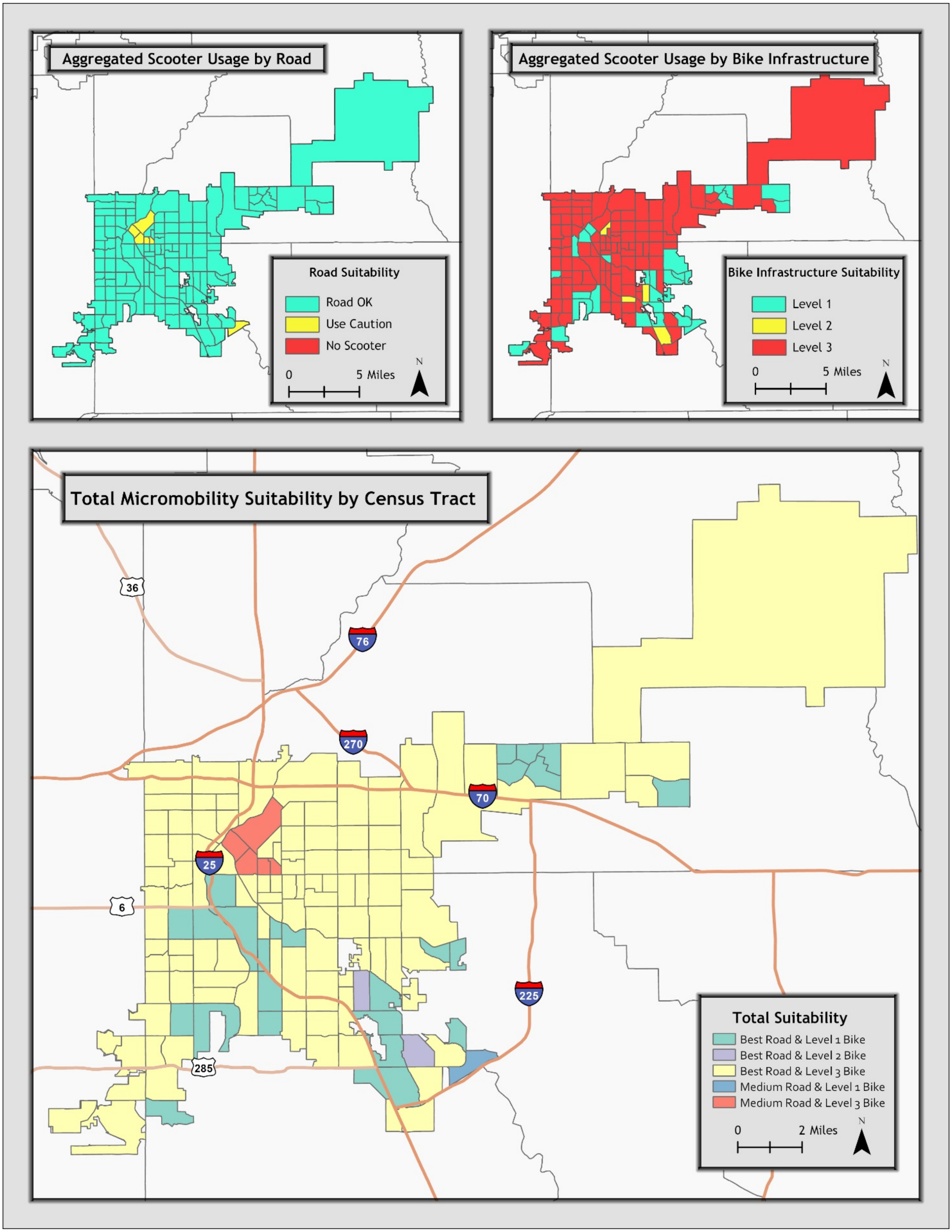


*Figure 1: Aggregated scooter usage by road, aggregated scooter usage by bike infrastructure, and total suitability by census tract.*

## Socioeconomic Equity

From the socioeconomic parameters from our analysis, our team is able to derive a map which suggests a preliminary spatial distribution of underserved census tracks across Denver. While these socioeconomic indicators are not completely representative of socioeconomic status, it does provide a baseline for targeting communities which have been underserved and historically underrepresented. Considering this analysis, we see that that 72 census tracks fall above the 50% when assessing their socioeconomic equity rank (average percentile). This finding suggests that when aggregated percentile ranks across all indicators, 72 census tracks fall above the 50% threshold. Additionally, there 31 census tracks are above 75% threshold in their socioeconomic equity rank (average percentile). Figure 2 displays the aggregated socioeconomic score range for each census track.

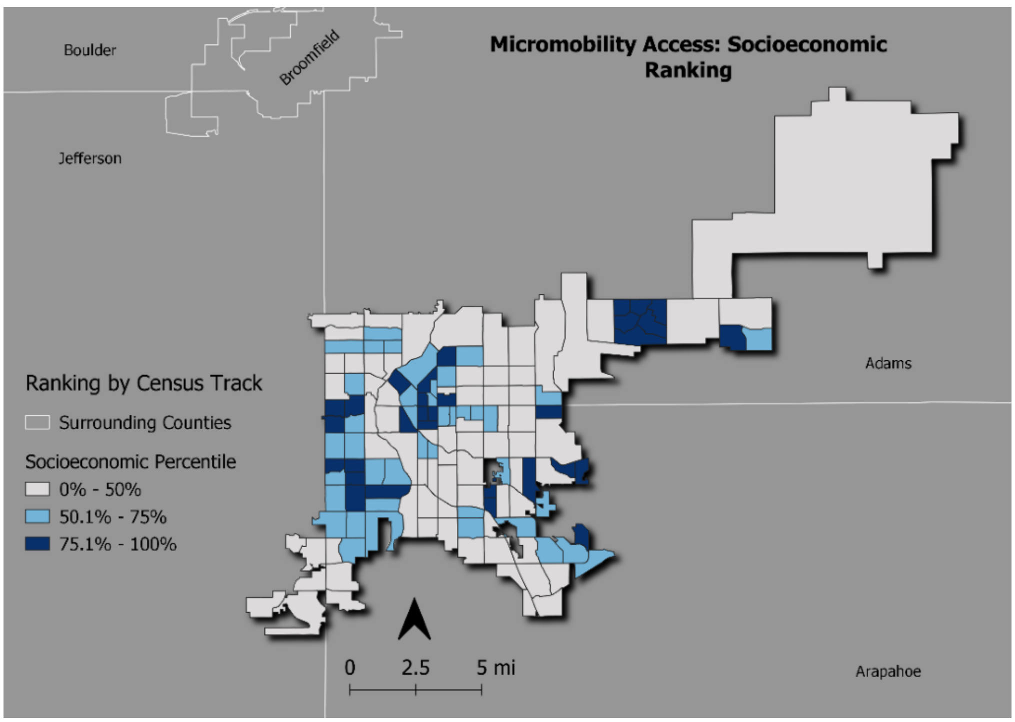


*Figure 2: Socioeconomic Indicator Ranking*

## Spatial Equity

Using a similar approach, spatial indictors are able to provide context about commuting behavior, public transit use, and car availability across the city. While these indictors do represent a portion of the spatial accessibility of transit services, they are only a suggestion and provide inferences about the true accessibility of transit services offered in an area. Additionally, indicators may not always be homogeneous across an entire census track. For example, residents living closer to transit stops may use public transportation while those living further away, but still in the same census track, may not. Here, our team find that 76 census tracks fall above the 50% threshold when assessing the spatial equity rank (average percentile). Additionally, no census tracks above the 75% threshold. Figure 3 displays these results.

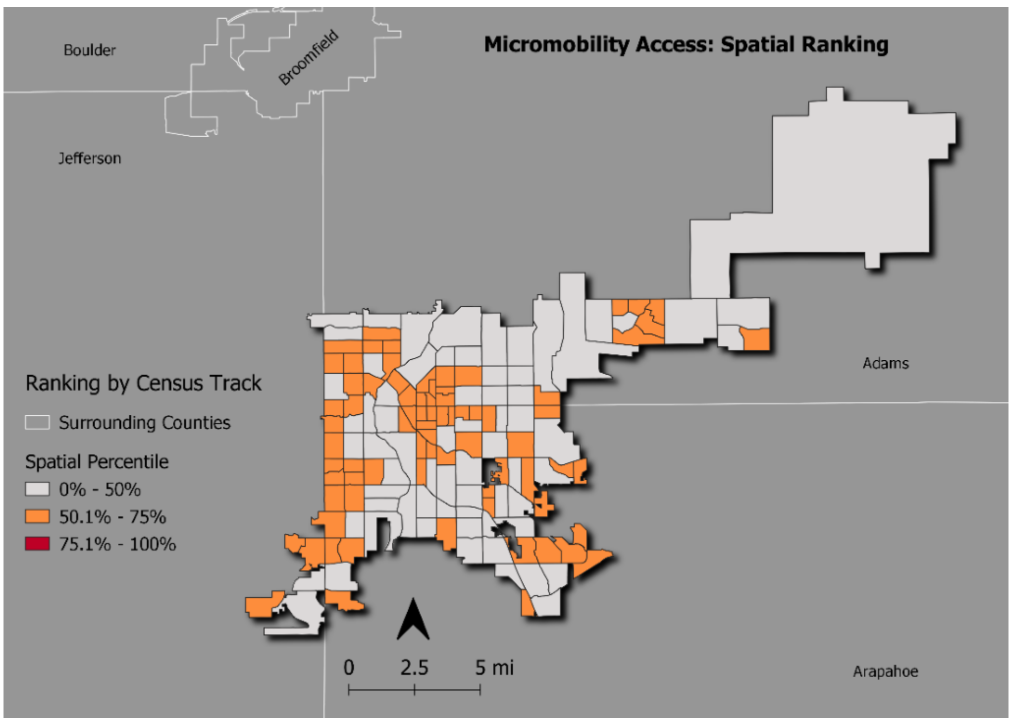


*Figure 3: Spatial Indicator Ranking*

## Combined Equity

While our separate socioeconomic ranking and spatial ranking maps provide valuable insight on the location of populations who are most likely to experience either socioeconomic or spatial barriers to transportation, our analysis is most concerned with the combination of both categories. Our combined socioeconomic and spatial equity analysis (Figure 4) reveals census tracts particularly vulnerable to transportation discrepancies and stand to benefit the most from improved access to micro-mobility. The census tracts found in the top combined equity percentile index (75% - 100%) deserve the most consideration and should be considered high priority areas for micro-mobility deployment (Figure 5). These areas include portions of southeast Denver, all neighborhoods in and immediately surrounding the central business district, as well as the West Colfax, East Colfax (Figure 5 – A), Villa Park, Indian Creek (Figure 5 – D) Westwood (Figure 5 – B), Mar Lee, and Montbello (Figure 5 – C) neighborhoods. These results are remarkably similar to the "Dockless Vehicle Opportunity Areas" illustrated in the Request for Qualifications Shared Micro-mobility report released by Denver Transportation and Infrastructure. We believe this indicates that our results closely align with the city's overall vision for the future of micro-mobility.

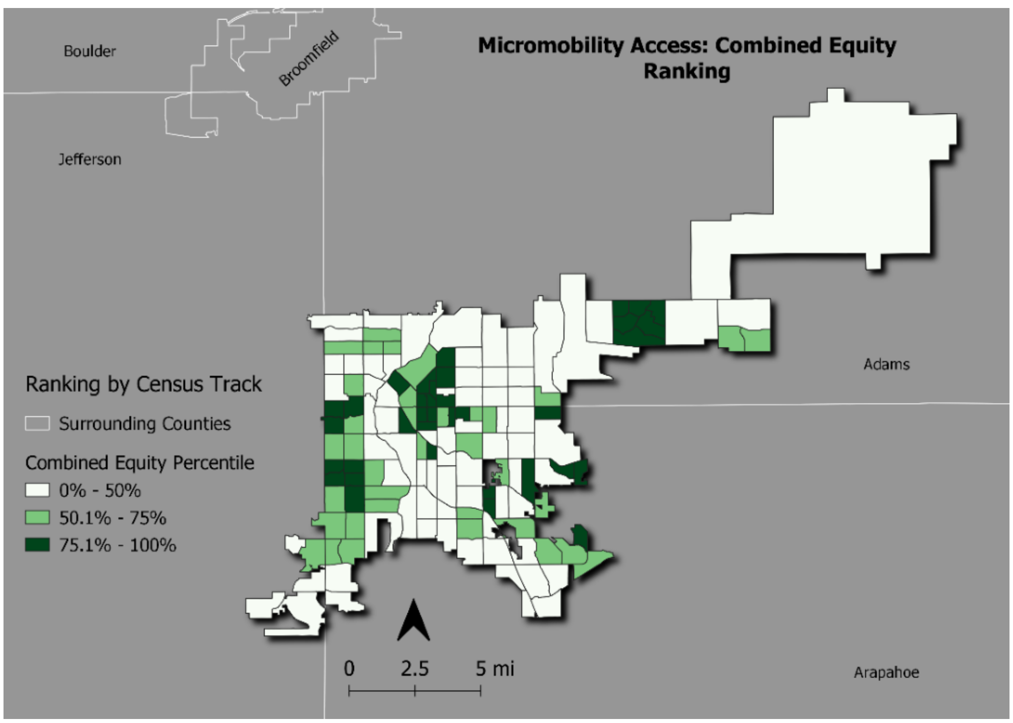


*Figure 4: Combined Indicator Ranking*

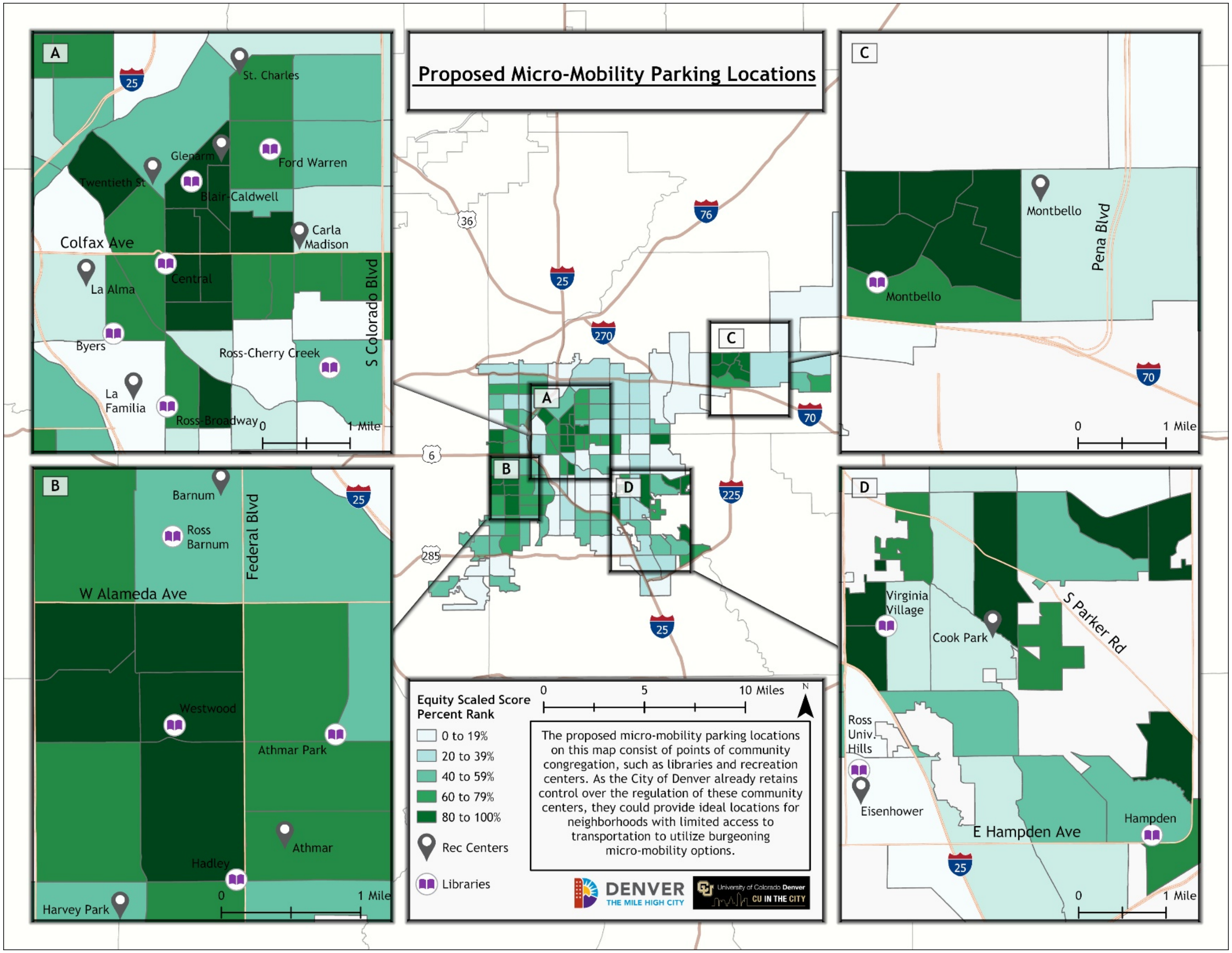


*Figure 5: The results of an overlay of the combined indicator ranking and points of community congregation such as libraries and rec centers.*

# Conclusion

Micro-mobility technologies like dockless electric bicycles and scooters have the potential to play a vital role in urban infrastructure and help to encourage a system-wide shift towards a more equitable and sustainable future for transportation. In Denver, these novel mobility services have the potential to accomplish goals listed in the city's MAP. By properly monitoring and evaluating ridership, city planners can better accommodate these services and extend them to populations which currently lack access. Moreover, it is important for city officials to play an active role in the management of scooter programs to ensure that these micro-mobility technologies are utilized to their full capacity. To investigate micro-mobility's potential to reach the city's goals our team conducted two analyses. In our first analysis, we examined the current state of road and bicycle infrastructure in Denver to determine if it favors micro-mobility as a prevalent form of transportation. Our second analysis considers transportation equity based on socioeconomic and spatial indicators to recommend priority areas for scooter deployment. Finally, we identified ideal locations for micro-mobility vehicle parking and docking stations within equity priority areas.

To investigate infrastructure suitability for micro-mobility our study centered around Denver city ordinance 14-1876, which bans scooter users from using the sidewalk unless the roadway speed limit is over 30 miles per hour and no bicycle infrastructure is available. To that end, we considered roadway speed limit, roadway type, and existing bicycle infrastructure within the city. Our findings suggest the majority of Denver's roadways are conducive to micro-mobility usage, meaning that Denver has plenty of non-arterial roadways with speed limits under 30 mile per hour. Conversely, our findings reveal that the majority of Denver's bicycle infrastructure does not contribute significantly to micro-mobility suitability. This is mainly because most of Denver's bicycle infrastructure consists of shared roadways without dedicated bicycle lanes. While this infrastructure is a step in the right direction, it does not provide the same level of safety as other forms of bicycle infrastructure and therefore electric scooter users who are unfamiliar with riding in the roadway may feel uncomfortable in these corridors and opt to ride on the sidewalk. Furthermore, we find that when infrastructure is aggregated at the census tract level, bicycle infrastructure only contributes strongly in less than 20% of census tracts. To finish, we combined bicycle and roadway infrastructure at the census tract level, which confirmed our previous findings. It should be noted that micro-mobility vehicle operators are more likely to violate city policy by riding on the sidewalks in areas where road infrastructure is classified as "Use Caution" and bicycle infrastructure is not thoroughly established.

To support Denver city ordinance 14-1876 and growing micro-mobility use within the city we recommend increasing investments in bicycle infrastructure, as this is most conducive to micro-mobility usage. Additionally, Denver is underserved in terms of separated bicycle infrastructure, which is the safest type for both bicycles and scooters. Adding buffered and protected bicycle lanes will not only help Denver reach its Vision Zero Program goals but will also assist in attaining Mobility Action Plan goals by reducing single occupancy drivers and encouraging residents to use bicycles and micro-mobility. Our team also recommends following through with a strategic observation analysis informed by the results of an infrastructure analysis. We recommend targeting corridors rated “Use Caution” or corridors with level 3 bike infrastructure and comparing rider behaviors in these corridors with that in more highly rated corridors. This analysis may offer city officials more insight into how infrastructure impacts micro-mobility use behavior.

Our transportation equity analysis examined several socioeconomic and spatial indicators to evaluate transportation accessibility on the census tract level for the city of Denver. The resulting maps highlight census tracts in the top 50th and 75th percentiles for socioeconomic, spatial, and combined socioeconomic and spatial equity ranks. These census tracts represent the highest concentrations of mobility disadvantaged groups in the city who could potentially benefit the most from micro-mobility services such as e-scooters. Furthermore, our results closely resemble the city of Denver’s “Dockless Vehicle Opportunity Areas”. Using information from the equity analysis and the opportunity area maps, the city of Denver has the potential to readily supply and support micro-mobility transit across the municipality.

Currently, micro-mobility vehicle deployment is concentrated in the CBD area of the city, while other neighborhoods that stand to benefit from their use have substantially less access to these vehicles. We recommend using these maps to aid future decisions regarding the development of e-scooter parking, docking, and deployment zones to encourage equitable access. We recognize that deploying e-scooter vehicles to these areas might come at greater costs to operators and suggest that the city create incentives to encourage a more equitable distribution of e-scooters. Incentives could include discounts on annual operator permits and/or vehicles fees. To further increase safe and equitable access to micro-mobility, we also suggest the city of Denver cooperate with micro-mobility operators and community members through the Denver Vision Zero program to educate residents on e-scooter access and safe usage. Micro-mobility has the potential to play an active role in the future of Denver’s transportation needs, and the information in this report provides the city with many opportunities to establish micro-mobility as a safe and equitable option for all.

# Data Documentation

| Dataset Title | Data Source | Analysis |
|---|---|---|
| Existing Bicycle Facilities | https://www.denvergov.org/opendata/dataset/city-and-county-of-denver-existing-denver-bicycle-facilities | Infrastructure |
| Lightrail Stations | http://gis-rtd-denver.opendata.arcgis.com/datasets/e14366d810644a3c95a4f3770799bd54_1 | Equity |
| Bus Stops | http://gis-rtd-denver.opendata.arcgis.com/datasets/e14366d810644a3c95a4f3770799bd54_2 | Equity |
| Street Centerline | https://www.denvergov.org/opendata/dataset/city-and-county-of-denver-street-centerline | Infrastructure |
| Census Data | https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml | Equity |
| 2018 Census Data | https://www.nhgis.org/ | Equity |