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Authors

Ferguson, Beth

Blandino, Jordan Scott

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Shared Micromobility Vehicle Design and Safety

Beth Ferguson, Associate Professor
Jordan Scott Blandino, Graduate Student

Department of Design, University of California, Davis

October 2025

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16. Abstract This study investigates the evolution of shared micromobility vehicle design and safety practices in the San Francisco Bay Area from 2017 to 2024. Shared micromobility includes e-bikes and e-scooters. Stakeholder interviews revealed that limited protected bike lanes, poorly designed or neglected e-bike and e-scooter fleets, deteriorating road infrastructure, and unsafe rider behavior have impeded the widespread adoption of shared micromobility in urban areas. There is a pressing need for consistent design standards for lighting, battery charging, braking systems, vehicle frames, and wheel sizing to further improve safety and vehicle durability. Recommendations include expanding protected bike lanes, improving road maintenance, offering e-bike riding lessons, promoting helmet use, and encouraging substance-free riding. Enhancing vehicle security and implementing battery safety protocols are also critical for improving charging accessibility and reducing theft and fire risks.			
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Shared Micromobility Vehicle Design and Safety

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Jordan Scott Blandino, Graduate Student

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Executive Summary

Executive Summary

This study explores the evolving landscape of shared micromobility in the San Francisco Bay Area and Davis, California, focusing on vehicle design, safety, infrastructure, and user behavior. Through stakeholder interviews, field testing, and design analysis, the research identifies key challenges and opportunities for improving micromobility systems. Shared micromobility services, including e-bikes and e-scooters, have grown rapidly due to their potential to reduce emissions and improve access to public transit. However, safety concerns persist, particularly around road conditions, rider education, and vehicle design. Poor infrastructure, such as potholes and disappearing bike lanes at intersections, contributes to accidents and discourages ridership. Conflicting speed limits between micromobility devices and motor vehicles often push riders onto sidewalks, creating hazards for pedestrians.



Figure 1. Lyft's Pillar bike and scooter dock featuring integrated vehicle charging located at 1350 Howard Street in San Francisco, CA

Vehicle design plays a critical role in safety. Larger wheels and shock absorbers improve stability and reduce pothole related injuries. Adjustable seat heights on bicycles accommodate a wider range of riders, while scooters lack flexibility in fit, posing risks for shorter users. Brake systems vary in effectiveness, with drum brakes preferred for shared fleets due to their durability and low maintenance requirements. Lighting systems

and integrated turn signals enhance visibility, but standards vary and are often insufficient for nighttime riding. Battery technology has evolved from warehouse-based charging to swappable systems and kiosk-based infrastructure. While these innovations reduce labor and emissions, they introduce new risks related to theft, vibration damage, and fire hazards. Best practices for battery safety include using UL-certified components, monitoring temperature, and avoiding overcharging.

Performance testing revealed that some scooters exceed the regulated 15 mph speed limit, and braking distances vary significantly depending on vehicle type and maintenance. Rider behavior plays a significant role in micromobility safety outcomes, with low helmet usage and reckless riding contributing to injuries. However, the unpredictability and negligence of car drivers also pose serious risks to micromobility users, especially in areas lacking protected bike lanes. Education programs, particularly in schools, are recommended to improve awareness of traffic rules, safe riding practices, and how to navigate shared roadways with motor vehicles.

The study concludes that micromobility remains a promising low-carbon transportation option, but its success depends on collaboration among municipal governments, service operators, vehicle designers, transportation policy makers, and public works departments responsible for road maintenance and infrastructure planning. Recommendations include expanding protected bike lanes, improving road conditions, promoting helmet use and rider education, implementing battery safety protocols, and standardizing vehicle design features such as wheel size, lighting, and braking systems.

Contents

Introduction

The goal of this research report is to share insights on ways to improve the safety of shared micromobility vehicle design. These insights are based on a literature review, an evaluation of physical device design characteristics, and interviews with stakeholders—vehicle designers, regulators, government officials, industry representatives, and members of pedestrian and bicycle advocacy groups.

Shared micromobility (bicycles, e-bikes and e-scooters) have the potential to reduce greenhouse gas emissions, traffic congestion, and air pollution, particularly when they are integrated with public transit and replace private vehicle use. The North American Bikeshare and Scooter Share Associate’s “2022 State of the Industry report” states that in 2022, at least 157 million shared micromobility trips were taken in 401 cities across North America with over 289,000 shared micromobility vehicles deployed. They estimate 142 systems have e-bikes and 285 systems have e-scooters in North America. The report calculates that shared micromobility offsets 74 million pounds of CO₂ emissions by replacing car trips and that 64% of riders report using shared micromobility to connect to transit. This makes micromobility an important climate tool that fosters more equitable public transportation. Figure 1 shows how shared micromobility ridership numbers have been consistently recovering from the COVID 19 pandemic.

A Review of Shared Mobility in 2023 (SUMC MLC, 2024) states that “while micromobility ridership continues to grow in many places, the underlying landscape is still extremely unpredictable, especially for private operators.” Due to reduced venture capital investments and high system operating costs, many companies like Jump, Bird, Spin, BCycle, and Link have reduced their footprint, been sold to other operators, been taken over by transit agencies, or shut down. Many cities have launched a variety of incentive programs with rebates to encourage private micromobility use with great success. City managers are still struggling to catch up with electric micromobility popularity so that safety and quality standards can be established and protected bike lanes be implemented.

Shared Micromobility Ridership in the U.S. and Canada, 2010-2022

IN MILLIONS OF TRIPS

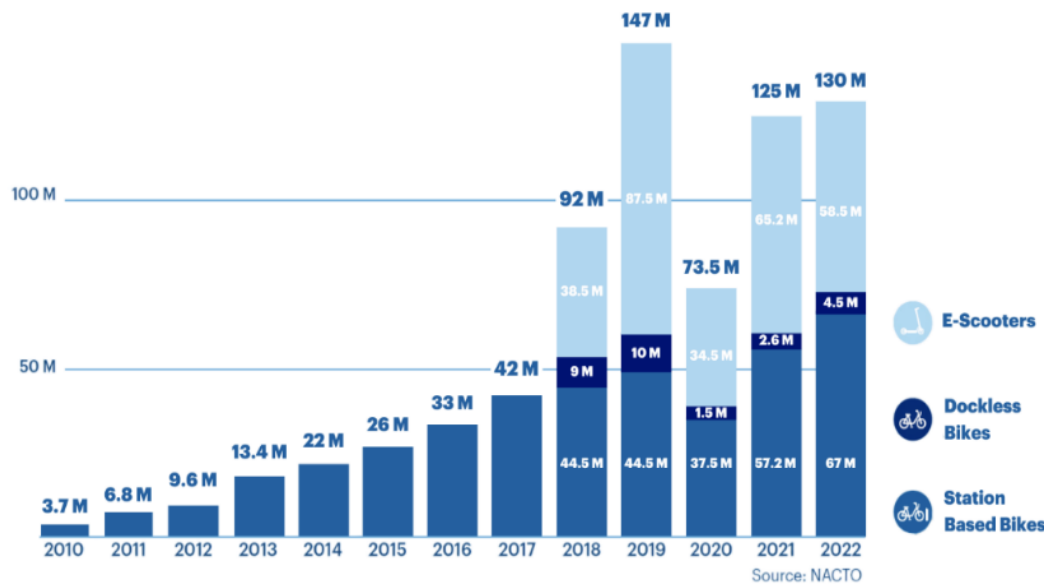


Figure 2. Shared Micromobility Ridership in the U.S. and Canada, 2010-2022

(Source: <https://nacto.org/publication/shared-micromobility-in-2022/>)

Shared and personal e-bikes and e-scooters have become popular for personal transportation, delivery workers, and leisure activities. The ability to capture rider safety data is difficult because of a lack of accurate ridership data and the fact that not all crashes or injuries are documented. The US Consumer Product Safety Commission’s report “Micromobility Products-Related Deaths, Injuries, and Hazard Patterns: 2017-2022” (Tark 2023) estimates that e-scooters caused 169,300 emergency department visits and that e-bikes, 53,200 emergency department visits during the study period. The study showed that victims reported common accident causes to be limited visibility, distraction by cell phone/music while riding, lack of helmets, and difficulty carrying something while riding. The report estimated that 233 deaths have been associated with micromobility devices. Other safety hazards highlighted include battery fire hazards, brake problems, miscellaneous product-related issues, car collisions, and road obstructions.

Industry stakeholders, policymakers, and academicians are imagining a more sustainable transportation system where mobility as a service (MaaS)—including shared micromobility, ride-hailing, and public transit—supplants private vehicle ownership as the dominant mode (Shaheen and Cohen 2018). Micromobility fleet operators have provided the public with a variety of shared e-scooters and e-bikes that help solve the last-mile challenge with transit catchment areas. The features of these vehicles vary, including size, speed, brake system, and lighting, which could have implications for user comfort and safety. This market would benefit from a comprehensive evaluation of the different e-scooter and e-bike features to further enhance safety guidelines.

An evaluation system would help transportation regulators know what safety features to look for and require before permitting micromobility operators in their cities, in turn improving safety for local riders and pedestrians.

This research investigation articulates best practices for e-scooter and e-bike design and safe user operation recommendations. The goal of our analysis and design guidelines is to help manufacturers and shared service operators improve their e-scooter and e-bike designs. We hope that this study will help city transit regulators and researchers understand how the different vehicle features compare and what to look for. Some vehicle designs offer safety measures like requiring two full kicks before the throttle button engages. This helps the rider avoid falling off. Other vehicles, like Spin's new e-scooter design, offer a back stomp brake which can reduce the distance needed to stop when combined with the handlebar brake. Furthermore, an option for riders to be seated could improve safety for people with compromised balance. E-scooters are popular for 1-2 mile trips, especially among the younger population. E-bikes are more commonly used for 3-5 miles trips and are more popular with an older population. The City of Oakland's website (<https://www.oaklandca.gov/resources/e-scooter-frequently-asked-questions>) provides rules for micromobility riders. A few examples are that a rider must use a bike lane if the road speed is greater than 25 mph, not ride on sidewalks, have a California driver's license, and wear a bike helmet. Only one person may use a motorized scooter at once and you can't carry a package. Vehicles should be locked to a bike rack or parked at a kiosk after the ride is complete, and riders should not be under the influence of alcohol or drugs.

Literature Review

We reviewed a range of literature related to shared micromobility safety and vehicle design, including industry and agency reports. Micromobility has surged over the last 7 years, due to technological advancement, including integrated smartphone apps, vehicle GPS for real-time tracking, and payment integration. Urban riders find these vehicles convenient, nimble, fun, and environmentally sustainable. We focused on how shared micromobility operators leverage rider apps and physical vehicle graphics to promote safe riding. Additionally, we explored new policies and agreements implemented by city managers to enhance shared micromobility safety on their streets. While existing literature primarily addresses rider behavior, road infrastructure, and economic models, our research aims to fill the gap by emphasizing vehicle design specifications and their safety implications.

Shared Micromobility Services



Figure 3. Safety and Parking reminders found on the Spin e-scooter and Lyft Bay Wheels e-bike

Rules and Regulation

Shared micromobility operators provide rider safety tips through in-app reminders and vehicle stickers, as shown in Figure 2. The Spin e-scooter sticker on the left in the figure reads: *wear a helmet, ride on the road, yield to pedestrians, obey all traffic laws, don't drink and ride, do not block the right of way or obstruct sidewalks, do not block access ramps or pedestrian pathways*. The Lyft Bay Wheels e-bike sticker on the right in Figure 2 reads, in English and Spanish: *yield to pedestrians, stay off the sidewalk, wear a helmet, follow the rules of the road, and beware of blind spots*.

Cities across the United States have different rules related to speed, the need for a driver's license, and helmet use for the permitted shared micromobility vehicles used on their streets. The use of e-scooters typically does

not require a driver's license to operate. However, policies do not guarantee that users receive sufficient training and follow instructions to safely operate an e-scooter. This lack of guarantee may be a key reason why about one-third of those injured were riding an e-scooter for the first time (Ma et al., 2021). In 2019, California passed a law, making helmet use optional for electric scooter riders older than 18 years of age, despite a study showing that only 4.4% of injured riders were documented to be wearing a helmet (Trivedi et al., 2019). New advanced vehicle sensors with speed detection algorithms and improved operating systems, including geofencing (whereby remote GPS controls the vehicle's speed) have allowed shared micromobility operators, in collaboration with city partners, to automatically enforce speed limits by reducing the vehicle speed in zones with many pedestrians.

Rider Behavior and Common Accidents

Responsible riding is essential for a safe micromobility experience, but it can be challenging for new riders unfamiliar with the rules of the road, the area they are riding in, or the vehicle they have rented. Accidents often occur in low-light conditions and are commonly associated with alcohol use, resulting in injuries that primarily affect the head, face, and upper extremities (Zube et al., 2022). Many studies indicate that shared micromobility riders do not use personal helmets. "Helmet usage tends to be lower among shared micromobility users" (Shaheen and Cohen, 2019). Riders might find it inconvenient to carry a helmet with them, especially if the rental was not planned when they left home.

Falling off the vehicle or colliding with other vehicles are the two common types of accidents and mechanisms of injury. Common reasons that riders fall off an e-scooter include uneven road pavement, collisions with fixed objects (such as trees) or conflicts with pedestrians or other vehicles (Yang et al., 2020). Factors affecting rider accidents beyond collisions with other vehicles or road obstacles include riding skills, reaction time, speed, and perception.

Accident Causes and Reporting

Accident reporting may or may not occur at the level of the rider, service operator, police, or healthcare provider, making it difficult to determine the exact number of shared micromobility accidents over the last 10 years. Unlike car crashes, which have relatively standard reporting procedures and databases, a much smaller number of e-scooter incidents were well-documented for analytics (Ma et al., 2021). According to the Consumer Product Safety Commission's Report on Micromobility Products, e-scooters resulted in an estimated 50,000 emergency department visits and at least 27 fatalities between 2017 and 2019. The study found that only 2% of e-scooter riders interviewed while receiving emergency treatment reported wearing a helmet compared to 66% of cyclists (Tark, 2022). A different study sample from UC Berkeley revealed that 83% of scooter-related emergency visits did not involve another mode, while 13.6% involved a motor vehicle, and 2.8% involved a pedestrian. The study suggested that scooter-related injuries are common, with varying severity, low rates of adherence to rider age requirements, and low rates of helmet use (Shaheen and Cohen, 2019).

Micromobility Vehicle Design and Safety

Equipment

Electric scooters and e-bikes began to emerge in the 2000s, with companies like Segway and Razor leading the way. However, they faced battery limitations due to their weight, slow charging times, and insufficient durability. Over the past five years, technological advances, industry investments, and rider preferences have influenced shared vehicle designs. These designs now incorporate longer-lasting, swappable lithium-ion batteries and sturdier frames capable of withstanding falls on the street. Today, features like payment apps, GPS, dockless rentals, charging docks, lights, and cargo baskets have contributed to the growth of the micromobility industry.

The shared micromobility vehicle design industry is dynamic and has undergone significant changes since 2017, when e-scooter companies began offering docked and free-floating rentals in cities around the globe. Vehicle designs have become more robust, accessible, and efficient at incorporating sensor technologies for safety applications (Sandt, at all, 2023). Key components to consider include steering handlebars, seating or standing platform, acceleration throttle or pedal assist, braking controls, and information displays for speed, availability, and battery status. The design and manufacturing industry has also adapted to create more inclusive vehicles for individuals with disabilities. In 2024, micromobility operator VeoRide conducted a study to enhance accessibility through vehicle form factors. They recommended diverse vehicle types to meet community needs, emphasizing features like throttles, low center of gravity seats, and large tires, which enhance accessibility for riders aged 45+ and for people with disabilities (VeoRide, 2024). Opportunities for further design improvements exist in vehicle size, component quality, night lighting, batteries, and operating systems. Vehicle maintenance is crucial to reduce brake failures, broken pedals, and wheel issues. Figure 3 shows the timeline of how the company Lime changed its shared vehicle from 2017 to 2020 to be more robust for riders.



Figure 4. Timeline of share vehicle design changes made of lime 2017-2020

(Source: www.li.me/blog/lime-announces-the-gen4-scooter-as-it-achieves-first-profitable-quarter)

Battery Safety

Lithium-ion battery fires can be a significant issue for e-bikes and e-scooters, especially from improper charging of faulty, illegal or unregulated devices. New York City saw an increase in personal e-bike fires from 44 in 2020 to 220 fires in 2022 (nyc.gov, 2023). City managers are advocating for federal regulation and education to improve battery qualities. In July 2019 Lyft Bay Wheels e-bikes were taken offline in San Francisco after two vehicles caught fire. This incident caused Lyft to switch to a different battery supplier. In 2024, China announced that they will improve regulations around battery quality by addressing issues such as battery overcharging, overheating, short circuits, thermal abuse, and battery puncture (Toll, 2024).

Environmental Design Challenges

City streets laid out over 200 years ago have limited space for bikes, buses, cars, delivery vehicles and people. “Sharing road space with motor vehicles is potentially hazardous. A person on a bicycle [or scooter] is much more vulnerable than the occupant of a car, who is protected by an enclosed box, seat belts, air bags and crumple zones, whereas the cyclist has no such protection. Thus, in most countries cyclists suffer a higher accident rate per kilometer than travel by other modes” (Tovey and Cooper, 2012). Micromobility could allow for the growth of inter-connections between transit networks while reducing acreage previously reserved for motor-vehicle parking. This in turn may enable cities to reallocate space for multi-modal transportation as well as additional social welfare needs, such as housing. Micromobility also can provide first/last-mile solutions for getting to and from public transit. E-scooters show promise for providing new opportunities to connect people and transit systems, but they also will require deliberate and effective efforts to ensure safety to prevent injury (Harasym, 2022).

Road Conditions

Road surface conditions like potholes or cracks in the pavement cause uncomfortable vibrations for e-scooter riders and sometimes accidents due to sudden braking under a varying forward force. “50% of interviewed riders believed surface conditions like a pothole or crack on the pavement contributed to their injuries” (Ma at all, 2021). Similarly, ten percent of injured e-scooter riders reported uneven pavement as the reason for their falls (Bloom et al., 2020). “Top causes [of crashes] were speed, losing control, and hitting a pothole or a stationary object such as a pole” (Basky, 2020). Most accidents happen to new riders not familiar with the challenge of balancing a stand-up scooter. “Compared to the cyclists’ smooth accelerations, e-Scooters’ quick changes in accelerations are risky by preventing riders from stably controlling the vehicle” (Ma at all, 2021).

Docked vs. undocked parking

Docked micromobility kiosks require street space, hardware integration, a locking system for the parked vehicle and equipment maintenance. Once the upfront investment is made, the kiosk offers a predictable and secure parking location that reduces sidewalk obstacles and can charge vehicle batteries if they have access to electricity. Systems with docks also require less labor because workers don’t need to go out to reposition the vehicles like they do with undocked fleets. Micromobility service apps require users to photograph and confirm their sidewalk or bike rack parking location in efforts to reduce vehicles from blocking sidewalks, driveways, and roads. Some app websites highlight preferred parking zones that city managers implement with the operator during contract negotiations.

Equity Considerations

Improving the safety and design of shared micromobility vehicles and street infrastructure such as bike lanes have important implications for transportation equity. Low-income communities rely heavily on public transit and active transportation (walking, biking), with lower rates of car ownership and longer commutes than middle-income communities. Shared micromobility, like e-scooters, has emerged as a potential solution for first- and last-mile connections to public transit as well as connecting underserved communities to jobs and services (NABSA, 2020; DuPuis et al., 2019; Smith & Schwieterman, 2018). Low-income communities often lack safe bike lanes and sidewalk infrastructure, putting users of traditional and new active transit modes at risk of injury or death (Braun et al., 2019). The San Francisco Municipal Transportation Agency (SFMTA)¹ is now requiring that permitted e-scooter operators offer adaptive scooters to 5% of their fleet. This will support the disability community to benefit from access to seated e-scooters and new form factors that fit a larger clientele in the micromobility space. More research is needed to determine the speeds adaptive scooters should travel at and whether sidewalk travel will be permitted, as with electric wheelchairs (4.5-8 mph).

¹ <https://www.sfmta.com/reports/guiding-principles-emerging-mobility-services-and-technologies-0>

Stakeholder Interviews

Method

We interviewed vehicle designers, regulators, government officials, industry representatives, and community stakeholders to gain insights into the context surrounding shared micromobility vehicle design and safety in the San Francisco Bay Area and Davis, CA. The semi-structured interviews were conducted via video conference and lasted 30–60 minutes. All interviews were recorded and transcribed. Government stakeholder interviewees included representatives from multiple cities in the Bay Area, while industry stakeholders comprised current and former shared micromobility operators. Community stakeholder interviewees represented pedestrian and bicycle advocacy groups in the San Francisco Bay Area.

Interviewees were asked: 1) Describe your role at your organization and its relevance to micromobility safety. 2) What are the number one safety problems that can happen with shared e-bikes and e-scooters? 3) What vehicle design safety features are important? 4) What do you see as the main challenges to integrating vehicle safety into shared micromobility? 5) Any other affordances or considerations you can think of that would improve the safety of the vehicle design? 6) What are ways to improve micromobility safety in cities?

Results

The interview transcripts were coded according to both pre-determined themes (i.e., questions the interviewer asked) and emergent themes. The following sections present the thematic analysis from these emergent themes:

- **Service Management:** speed profile, maintenance, cost, vehicle locking system
- **Vehicle Design:** rider fit, component choices, ID, policy of wheel size
- **Rider Behavior:** education / helmet
- **Environmental Factors:** cars, road quality, nighttime, sufficiency of bike lanes

Service Management

Speed geofencing

One interviewee mentioned that speed geofencing in the vehicle's operating systems allows managers to override the acceleration and to reduce the vehicle's top speed from 15 mph to 7 mph in a busy pedestrian traffic zone.

So on the shared system, we actually have authority and control to dictate a lot of different things. We can decide where they go and where they don't go. We can decide what speeds they go and where. So we can designate slow zones where they go 7 mph. We can designate no ride zones where vehicles will cease to give assistance.

This remote speed geofencing feature helps city and university managers ensure that e-scooters and e-bikes will not overtake classic bikes and pedestrians in busy areas. The sample interviewee mentioned that it is important to manage *“how the electric assist comes on so that it doesn't startle the rider, especially getting people who are less experienced onto these things, I think there's a lot of opportunity for failure in that space. And I think the better shared operators recognize that and bring conservative power profiles onto their devices.”*

Accident Data

Multiple interviewees mentioned the problem for stakeholders to collect accurate accident data.

There's a data collection problem when officials go out to handle crashes. I think we're working with our fire, police, and campus to better the data collection process, so we know more about what kind of devices are getting into what kind of crashes. I think we have heard some dithering through data available from our student health and community student health and counseling services that there's been some uptick in folks coming in reporting crashes on e-scooters. It is hard for us to distill. Is that personal scooter use or shared scooter use? And so we're actually waiting to get some detail from Spin about what crashes have been reported to them to try to tease out from the student health data what of the increase that we're seeing is from the shared scooters becoming available, or is it from the personal scooters being adopted?

One industry stakeholder interviewee mentioned that if multiple people put in tickets through the app on some kind of injury, then the company needs to talk to the city's Department of Transportation to provide evidence or a plan on what the company will do to mitigate the issue.

One interviewee observed that maintenance quality can fluctuate depending on the budget of the operator and that this has been a challenge over the last few years as companies struggle to reach profitability in a challenging environment.

Maintenance

Multiple interviewees mentioned that vehicle maintenance happened when the vehicle was picked up for recharging or a battery was swapped out on the physical vehicle. The apps allow riders to indicate if the vehicle has a problem and that notifies the maintenance personnel.

When the transportation manager interviewee was asked what they looked for in a vehicle, they responded,

I look for something that can survive in the elements. Is it something that can handle weathering? Is it something that can be robust enough that if the bike falls over several times, nothing gets broken or worn out...and then how quickly can it be put back into service after it? If it goes into disrepair, are you replacing parts, or are you just readjusting it?

We heard from one city stakeholder that they thought the classic bike in the Lyft Bay Wheels bikeshare program to be robust with only occasional issues from normal wear and tear. One example was that the pedals get loose sometimes due to the vehicle being tipped over. They explained that with the arrival of e-bikes a few problems with brakes and battery fire issues led to vehicle recalls that have been fixed since the battery manufacturer was changed.

One interviewee mentioned the benefits of a shared vehicle vs. a personal vehicle related to maintenance

There's not a good maintenance network for anyone who owns their own device, versus the shared devices.... There is a maintenance team at a micromobility service provider warehouse that knows the ins and outs of keeping shared devices in service. Personal e-scooters are tricky because there's no education on the ABCs of scooter repair. It's hard to fix handlebar movement, breaks or put air into the tires, if the tires can even have air. People do not know what to do with worn out tires or where to find help with electric motor or battery repairs. One of the big benefits of the shared systems is that someone else is keeping an eye on your vehicle safety and maintenance.

One interview highlighted, “One thing to keep in mind is that these bikes never get to live inside unless they're specifically being worked on, so whatever weather events occur, they're basically completely exposed to it, and so that accelerates the rate of failure that you'll see”. They also said that “Any path of moisture ingress can cause problems for electronics” and that salting the roads in the winter “creates a situation where the plates are so corroded that you go to dock a bike, and then you put a bunch of force into it to dock it in the entire docking station just kind of comes down in front of you, and so regular replacement, and regular maintenance is a huge thing.”

“With vehicles living in the street, anyone can come up and vandalize them or throw them off anything, and people do. They're not in great shape and that can lead to failures occurring in the vehicle.” “We rely on the companies to do their own quality assurance, and I don't think they do as good a job as they probably should.” “We had a couple of blind people that fell over the scooters and sued us. That was part of what led us to be among the first wave of cities to require (digital Bluetooth) locking mechanisms on the vehicles”

Cost

The interview did not specifically focus on the rental cost of shared micromobility but the issue came up in relation to the company's ability to maintain profitability without compromising vehicle maintenance. One interviewee said, “I think right now it is somewhat expensive, but at a point the vendor is trying to break even.” Another interviewee said,

Something has to balance out between the profitability of the product versus what the safety requirements are. When you're thinking about a for-profit company, they're going to use the thing that is as safe as it needs to be for the least amount of money which doesn't necessarily result in the best product. It results in a usable product that is reasonably priced. There are really good equity programs built into our cost structure. So anyone who qualifies can get discounted rides that actually makes it reasonably affordable. It makes it so that it does rival

at least personal ownership costs versus at regular use [cost] personal ownership is pretty quick, probably a much more viable solution.

Theft of Batteries and Vehicle Parts

Batteries on e-bikes, e-scooters, and in the bikeshare kiosk are frequent targets of theft. One industry expert explained that using a geofence around a street with “chop shops” significantly reduced theft. It is a challenge to design a swappable battery system that prevents theft and is still easy to use. Manufacturers use a variety of tamper proof hardware and have tried to use parts that do not work on normal bikes.

One fleet manager explained the ways the physical bike lock can reduce theft by having the lock pass through the back wheel so that the vehicle does not roll when not activated. The use of alarms on the vehicle if it has been pushed over or tampered with has also reduced attempts at theft.

Vehicle Design

Multiple stakeholder groups explained the complex challenge of designing a shared micromobility vehicle that meets multiple criteria: one-size-fits-all, component quality, durability to withstand use and harsh weather. Heavier shared vehicles are less prone to theft, though they can be more cumbersome to ride and take longer to stop. Traditional bike stores sell classic bikes that are designed to be lightweight, efficient, custom-fit to the rider, and stored inside when not in use. One interviewee mentioned that shared vehicle designs try to create a form that fits people measuring 5 feet 2 inches to 6 feet 3 inches and know the vehicle will be less safe or manageable for people outside that height window.

During interviews, several experts emphasized the significance of safety in designing shared micromobility vehicles. Collaborative efforts between cities, operators, and manufacturers have led to notable improvements. For instance, earlier scooter designs featured 6–8 inch wheels, which frequently got caught in potholes. In response, the cities of Oakland and San Francisco implemented a requirement for 10–12 inch scooter wheels, a change that the industry swiftly embraced. As a result, injuries related to scooters—many of which were caused by potholes—have declined.

One interviewee said,

The bicycle form factor is almost 200 years old and is relatively safe. The issue is mostly just people in cars running into people on bikes. It is not really the bikes themselves that are an issue. The scooter is a much newer form factor that has more injuries per mile, and more safety issues partly because the first couple of generations of vehicles were not really designed for a public sharing. The early scooters weren't very robust and had relatively small wheels that didn't work well with potholes. We were the first city to mandate a minimum wheel size of at least 8 inches. Some of the early vehicles had 6-inch wheels. The 8-inch wheels are a lot safer and going bigger is even safer. Shocks are also useful for navigating potholes. The scooter industry is moving towards more robust vehicles with shocks and bigger wheels.

One interviewee who works with college campus transportation planning said,

We wanted bikes that would be easy to ride, and scooters that could be easily ridden, and really paid attention to their power portfolios when they turn on, so that they don't jolt a rider off but there still is a noticeable motor kick that an inexperienced rider will not lose control. Bikes just fit everything a lot better. I think, understanding the full portfolio of bikes, all the different shapes, dimensions, packages... I think there's a much broader capacity that bikes have to move people. A scooter is a fairly static item. ... I think one of the things that really fails in a lot of these things is they address the movement of people kind of convinced that people don't need to ever carry anything.

Another interviewee commented on *Bird* scooters in Davis in 2018: “The scooters weren't necessarily where we wanted them to be, as far as safe scooters. They had rigid frames. They had really small, rigid wheels. They had kind of funky geometries, and they weren't necessarily something that would work great for a varied-condition roadway network.”

Headlights

One interviewee explained that “Lighting systems are not super highly rated...It's something that is [designed] to basically aid in other people being able to see you, and much less the concern that you are able to see.” They said it was a “state-dependent thing and that the different distances the reflectors are rated up to. I think in California ... it has to be visible with a certain wattage at 300 feet...But that's something that will, again, vary state to state, so it's not a very regulated thing.”

Given where the bikes and scooters are deployed—most of the time it's in a fairly dense urban setting—lighting infrastructure is provided by the city, so there's some kind of peripheral lighting system that helps. When you get someplace that's like an enclosed bike path [with less lighting] I would say that the lights that we have are good enough to allow you to see what's on the ground maybe 15 to 20 feet in front of you, which, as long as there's not any kind of crazy obstacle in the way, should be enough.

Battery Technology

In 2018, most shared vehicles required the entire vehicle to be transported by van to a charging center in a warehouse. In 2024, the experts interviewed in this study explained that most shared micromobility vehicles in the Bay Area have a swappable battery system that is replaced by rebalancers after they receive a low battery notification. We heard that vehicles with swappable batteries are still vulnerable to theft and battery connection damage from excessive vibrations resulting from normal use on roads with curbs and uneven surfaces. One expert we spoke with said their company was testing charging kiosk infrastructure to reduce labor and the wear and tear of the current battery swap out system. A charging station kiosk would reduce operating costs, require less monitoring, and make it easier for the users to find the vehicles.

Rider Behavior

User behavior combined with the inadequacy of bike lanes in certain situations and the unpredictability of drivers...There's no way for me to understand what other people are going to do. You can have civil engineers make the city as bike lane-friendly as possible, you can put blocks between the lanes or some type of physical obstruction between the bike lane and the roadway, and you will still have people find every possible way to eschew that.

We asked our stakeholders about rider behavior and one industry representative said,

For the most part the vehicles are very safe. It has a lot more to do with how people ride them and how people use them. I would honestly say that, like the speed rating of a lot of things, [the speeds they can reach] make them more unsafe to ride, just because people ... want to use every vehicle to kind of go as fast as they possibly can. That can result in people maneuvering the vehicle recklessly at high speed.

A different interviewee said rider body position is key to safety. They said riders that keep their legs bent use their body as natural suspension. They also explained that devices have improved over the years and are easier to ride but still have issues due to them being tipped over in the street.

The scooters kind of put you on the device in an odd manner. You're standing sideways, but you must hold it forward. So, it's kind of like a skateboard, where you steer with your weight. It's not as organic as trying to counterbalance a bike. The devices have gotten a lot better in the last 6 years. They have improved manufacturing quality, larger wheel size, suspension, and brakes that work better. Those are some of the things that I think we didn't see back in 2018 that we see on devices now in 2024.

Honestly, one of the biggest problems I think that we've seen is just some of the vehicles being heavy and ... people being careless, basically dropping the bikes on their side. So, for a while there was an issue with bent crank arms, and to some degree crank arms falling off because of the force from the fall.

The interviewee went on to explain that riding a bike with a bent crank arm is awkward.

You can't accelerate as quickly, and that can cause some issues. For example, if you make a silly decision, and you think you can get through an intersection when you're not supposed to, but you don't have as good control of the vehicle as you think you do, you might not be able to accelerate as quickly out of an unsafe situation.

Helmet use

It's not something that everyone is going to do: carry a helmet around for 2 scooter trips or 2 bike rides that they do per day. It's much easier for me where I can lock [my helmet] up with my [own] bike... I can't leave my helmet on a shared bike and expect for my helmet to be there when I go back, because someone else might have gotten it.

Education

Multiple stakeholder groups believed that many micromobility users were unclear about the traffic rules and where they should ride, and they seldom wore bike helmets. The stakeholders recommended that training programs should be offered in high schools, so that students could learn the rules of the road.

One interviewee said, “I teach bike safety classes and one of my students asked me why they did not feel safe driving their new e-bike on roads shared with cars.” The interviewee explained,

Fast urban riding with potholes is challenging on a scooter and that the center of gravity for a scooter is much different than [for] a bike.

We don't require any bike education for people to go out and ride a bike unlike driving [a car] where you have to pass a test. Biking is an inherent right. [It's] kind of [the] same thing with scooting. Yet we let folks get onto these with just a very simple, ‘Give us your credit card. Let us scan your ID so we know who you are, and off you go.’”

Environmental Factors

The quality of the road, unpredictability of car drivers, and lack of bike lanes are common micromobility safety concerns we heard about from experts across our focus areas. On many urban streets, speed limits exceed 25 mph, which poses risks for e-bikes and e-scooters fixed at 15 mph in the same lane. Consequently, riders often opt to use sidewalks to avoid fast-moving traffic in locations without protected bike lanes. However, this practice presents challenges for pedestrians, who must contend with swiftly moving bikes and scooters. Additionally, parked e-bikes and e-scooters on sidewalks have been known to create tripping hazards.

One interviewee mentioned, “Shared scooter and bike designs are improving. If cities want to bring in micromobility they need to improve the street infrastructure so that people feel safe biking on the streets.” The interviewee felt that more people drive cars because they do not feel safe biking on streets shared with cars. They added, “Main streets need separated bike lanes so that bikes can safely get across main thoroughfares. Bike lanes disappear at the intersections where they are most needed.” The interviewee also mentioned that some “streets are in terrible shape with loose gravel and potholes. It makes a really big difference for streets where people are biking to be in good condition for people to feel safe.”

We heard from a different interviewee that mode separation between cars, bikes, and pedestrians was key to micromobility safety. “We’ve got a third class of vehicles emerging. We don’t just have bicycles and pedestrians, we have individual mobility devices that are faster and more dangerous than just a bicycle, and pedestrians really want to avoid getting side swiped.” They explained that cities are expecting a scooter limited to 15 mph to share a lane with a car going 35 mph and that it is not working safely. They gave the example of the Berkeley bike and pedestrian bridge that divides the two modes of mobility into a bike lane and a walking zone.

Charging Kiosks

One interviewee mentioned that Lyft Bay Wheels has installed a kiosk on Howard Street in San Francisco. This kiosk can charge parked e-bikes through the new charging dock design. The charging station dock helps reduce the need for swappable batteries, thereby reducing labor expenses and greenhouse gas emissions from service vans during rebalancing and recharging. We heard that docked vehicles are less likely to be damaged from falling over, which also helps reduce trip-related lawsuits to the city. Additionally, the kiosks assist riders in locating vehicles without solely relying on the app to track down undocked bikes. Equitable placement of these kiosks near public transit hubs and in diverse neighborhoods is a priority. Connecting the kiosks to city electrical grids can be an expensive challenge, but in some cases, off-grid solar power may be a viable option if there is sufficient sun exposure.

Vehicle Observations and Testing

Method

We observed and test-rode available shared e-scooters and e-bikes in the San Francisco Bay Area and Davis, California. Table 1 shows the five shared micromobility operators with coverage in our research area. The included companies are Spin, Lime, Link, Veo, and Lyft Bay Wheels. For each of these vehicles, the research team recorded physical dimensions, and the features and attributes found on the various vehicle designs. Additionally, we conducted vehicle performance tests to record and evaluate rider experiences related to acceleration and stopping.

Table 1. Shared e-scooters and e-bikes in the San Francisco Bay Area reviewed in this study

	Spin (electric assist)	Lime (electric assist)	LINK (electric assist)	Veo (electric assist)
E-scooter				
	Lyft Bay Wheels (non-motorized)	Lyft Bey Wheels (electric-assist)	SPIN (electric-assist)	Veo Cosmo 2 (adaptive scooter)
E-bike & Adaptive Scooter				

Vehicle Features and Measurements

We measured six aspects of the vehicle designs that affected rider fit, as illustrated in Figure 4. These dimensions included:

1. **Handlebar Width** - Horizontal distance between the outermost edges of the left and right handlebar grip areas.
2. **Handlebar Height** - Vertical distance from the ground to the level of the handlebar grip area
3. **Deck Size** - Length and width of a scooter's flat surface where riders may place their feet while riding.
4. **Wheelbase** - Horizontal distance between the points of contact to the ground for front and rear tires of the vehicle.
5. **Ground Clearance** - Vertical distance between the ground to the lowest point of the underside of a scooter deck.
6. **Wheel Diameter** - Greatest distance between the outside diameter of the vehicle tires.

For the three bicycles included in this study, we also measured the minimum and maximum range of adjustable seat heights. This measurement was taken from the top of the seat surface to the middle of the crank arm fixing bolt to the ground. For Veo's adaptive scooter, the seat height was non-adjustable and was measured from the top of the seat to the ground surface.

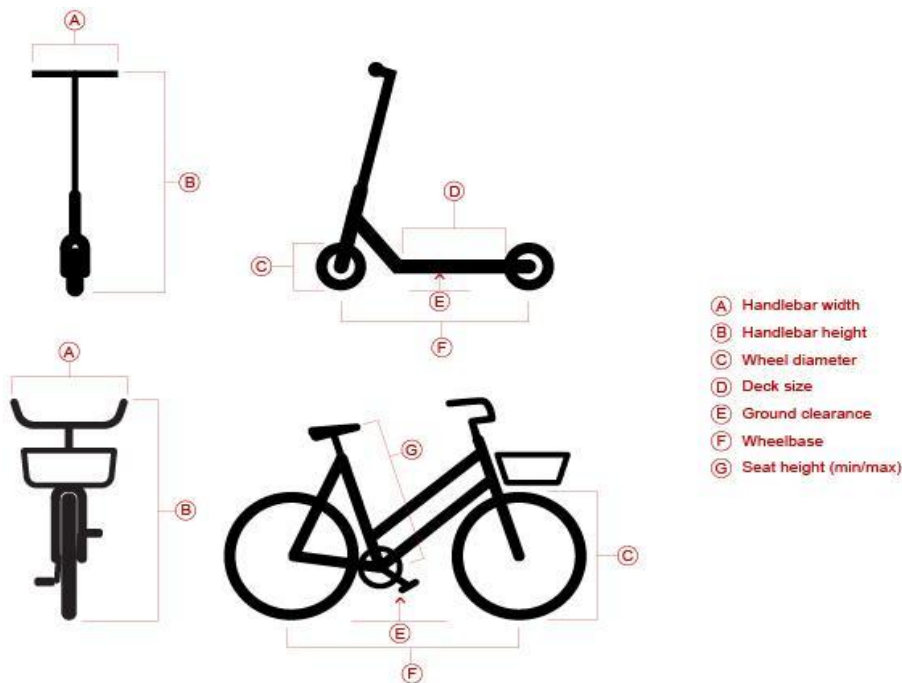


Figure 5. Bike and scooter dimensions measured during field testing

Vehicle Features and Measurements Results and Discussion

Table 2 and Figure 5 show the recorded dimensions identified in this study. Scooters appear to conform to similar sizes and dimensions in their designs. For example, the handlebar height of scooters were within a 2-inch variance, ranging from 46 to 48 inches. Scooters mostly featured 10-inch wheels (an increased diameter from early iterations of shared e-scooter designs). Handlebar widths were consistent for each type of micromobility vehicle, with a variance of 3.25 inches for scooters, 1 inch for bicycles. The flat deck size of scooters was identical in width but varied in length by up to 8.5 inches.

A bicycle's form factor allows for a wider variety of design permutations while remaining functional, compared to scooters. For example, bicycles have many different wheel sizes ranging from 20 to 29 inches with unchanged rider fit. With scooters, at a certain point, increasing the wheel size will affect the geometry and fit more dramatically.

Table 2. Measured Dimensions: Scooters (all measurements are in inches)

	Link	Lime	Veo	Spin S-100	Spin 6
Handlebar Width	23	19.75	20.5	20.5	22
Handlebar Height	47	47.25	48	46	47
Deck Size	7 x 24.5	7 x 17.5	7 x 19.5	7 x 19	7.5 x 16
Wheelbase	41	35	36	36.5	41.5
Ground Clearance	3.75	4	4	3	4.5
Wheel Diameter	10	10	10	11	10

Table 3. Measured Dimensions: Bicycles and Adaptive Scooter (all measurements are in inches)

	Bay Wheels (non-motorized)	Bay Wheels (electric-assist)	Spin S-300 (electric assist)	Veo Cosmo 2 (adaptive scooter)
Handlebar Width	25.5	26	26.5	39.5
Handlebar Height	43.5	43.25	41	42.25
Seat height (min/max)	31 / 41.5	31.5 / 42	29.5 / 39.5	27.5 (non-adjustable)
Wheelbase	45	45	47	46
Wheel Size	26	26	26	18

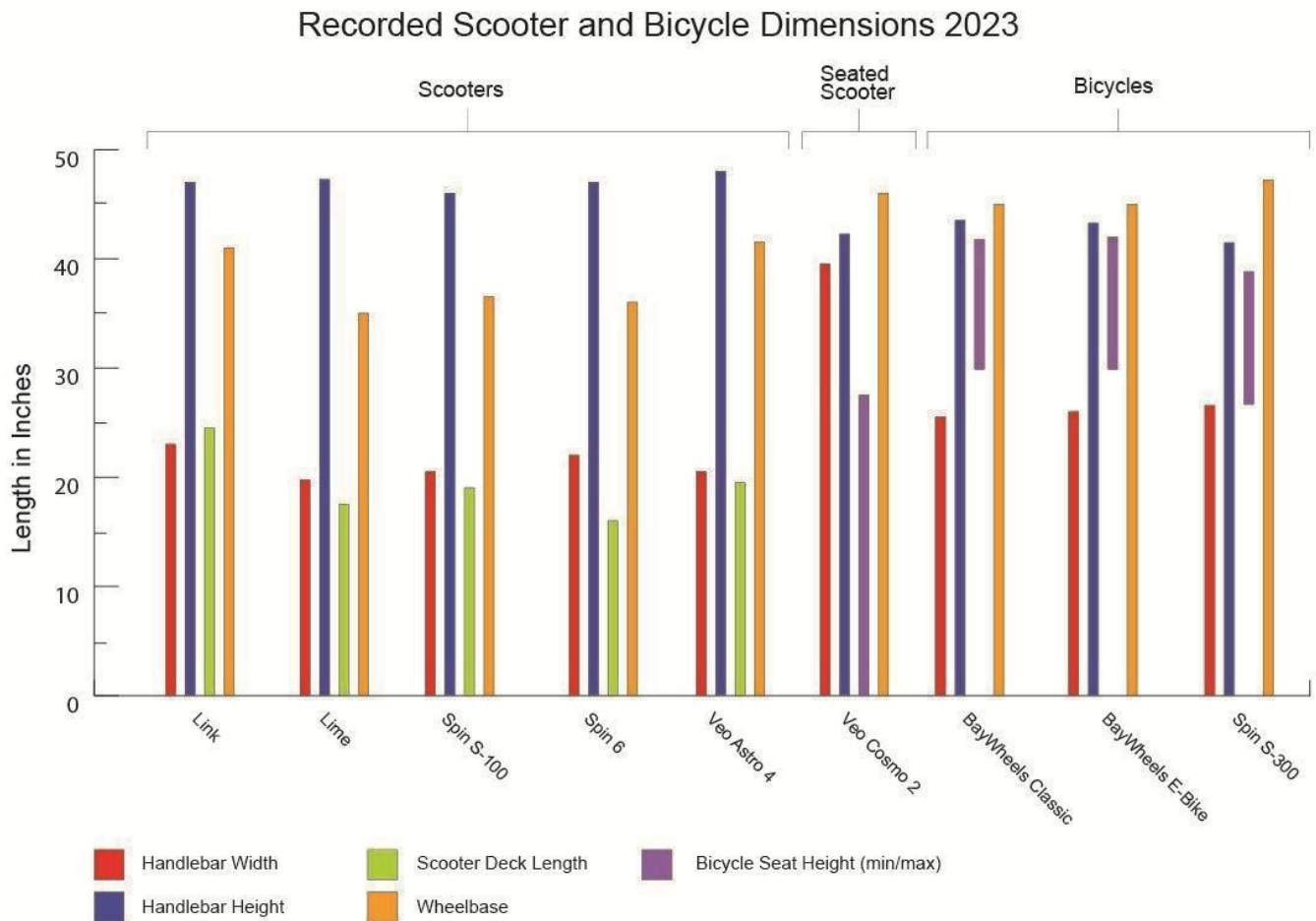


Figure 6. Chart with dimensional measurements of handlebar widths, handlebar heights, wheelbase, scooter deck length, and seat heights of devices measured in study area

In addition to measurements, we recorded various features, components, and attributes of the vehicles tested in this study. Figure 7 illustrates where these items are located. The features and attributes we recorded include:

1. **Braking system type** - Drum brake, disc brake, rim brake, etc.
2. **Presence of electric drive assist/drive assist location** - Front hub motor, rear hub motor, bottom bracket motor, etc.
3. **Electric Motor control** - Pedal assist, twist throttle, lever throttle, etc.
4. **Presence of speed display** - Style and location
5. **Lighting Systems** - Front light, rear light, turn signal, under-vehicle lighting
6. **Auditory Signals** - Bell, horn, functional indicator, etc.

7. **Kickstand** - Location and style (single leg, double leg, etc.)
8. **Fender/mudguard** - Full converge/partial coverage
9. **Cargo capacity** - Basket, rack, etc
10. **Suspension system** - Front or rear suspension
11. **Tire type** - Pneumatic or solid
12. **Lock** - Type, location, method of operation
13. **Battery** - Location, “swap-ability”, etc.

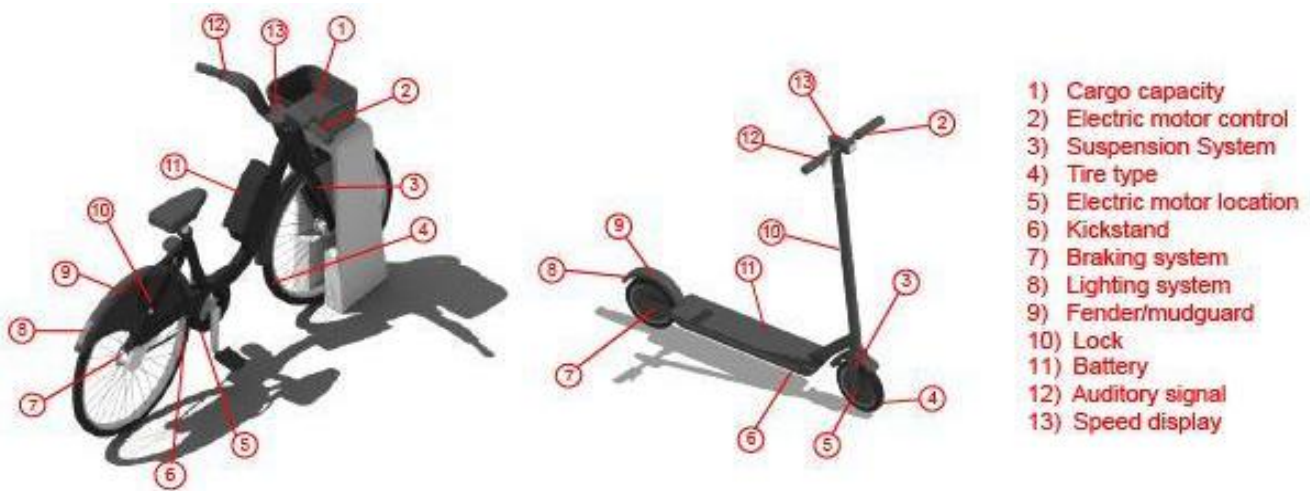


Figure 7. Locations of features recorded on bikes and scooters

Table 4. Presence of features on shared e-scooters

	Link	Lime	Veo	Spin S-100	Spin 6
Cargo Capacity	X (Basket)				X (Bag hook)
Throttle	X	X	X	X	X
Suspension	X	X	X	X	X
Tire Type	Solid	Solid	Pneumatic	Solid	Solid
Motor Location	Rear hub	Rear hub	Rear hub	Rear hub	Rear Hub
Kickstand	Single leg	Single leg	Single leg	Dual leg	Dual leg
Brake Type(s)	Drum	Drum	Drum	Drum	Drum
F&R Lighting	X	X	X	X	X
Turn signals					X

	Link	Lime	Veo	Spin S-100	Spin 6
Fender/Mudguard	X	X	X	X	X
Lock	X	X	X	X	X
Battery Location	Deck	Deck	Deck	Deck	Steerer
Hot-swappable Battery					X
Auditory Signal	X	X	X	X	X
Speed Display		X	X	X	X

Table 5. Presence of features on Shared bikes

	BayWheels Classic Bike	BayWheels Electric Assist	Spin S-300 e-bike	Veo Cosmo Adaptive Scooter
Cargo Capacity	X (basket)	X (basket)	X (basket)	
Throttle			X	X
Suspension				X (fork)
Tire Type	Pneumatic	Pneumatic	Pneumatic	Pneumatic
Motor Location	N/A	Front Hub	F&R hubs	Rear Hub
Kickstand	X	X	X	X
Brake Type(s)	Drum F&R	Disc front/Drum rear	Drum F&R	Drum F&R
F&R Lighting	X	X	X	X
Turn Signals				X
Fender/Mudguard	X	X	X	X
Lock	X	X	X	X
Battery Location	N/A	Frame downtube	Frame downtube	Seat pillar
Hot-swappable battery		X	X	
Auditory Signal	X (bell only)	X (bell only)	X (bell & speaker)	X
Speed Display				X

Vehicle Performance Testing

We conducted vehicle performance testing on the shared micromobility vehicles in the San Francisco Bay Area (Figure 8). Vehicle riding test site locations were chosen that met the following criteria:

1. Flat/level surface to remove influence on speed of the test vehicle introduced by ascending or descending a sloped surface
2. Location out of busy roadways used by cars, for safety of the test rider
3. Area longer than 200 feet to allow adequate distance for test vehicle to achieve top speeds and subsequent braking operation
4. Proximity to good availability of test vehicles to allow easy selection and exchange of test vehicles.



Figure 8. Vehicle speed and break testing, July 2023

Vehicle Speed Evaluation

California regulations limit the speed of shared e-bikes and e-scooters to 15 miles per hour. To verify compliance and assess the accuracy of on-board speedometers, we mounted GPS cycling computers (Wahoo Roam and Garmin Edge 510) to the handlebars of test vehicles, including Spin e-scooters (see Figures 8 and 9). Many vehicles featured digital speedometers, which were compared against GPS data during field testing.

Test riders recorded ride metrics by traveling in long, straight paths to reach maximum speed. They visually noted the highest speed shown on the vehicle's speedometer and compared it with GPS readings. This method allowed us to evaluate both the accuracy of speed displays and adherence to the regulated speed limit.



Figure 9. Documentation of GPS computers mounted on a Spin e-scooter during testing

Speed Test Results & Discussion

Table 6 shows that Link and Veo e-scooters reached 15 mph, Lime reached 16 mph, and Spin reached 17 mph. Sit-down scooters and bicycles achieve higher speeds, with non-motorized bicycles exceeding 15 mph under pedaling effort from the rider. Motorized bicycles approached car traffic speeds (25-30 mph). The higher speeds of bicycles depend on rider input and use of the gear-changing systems. Compared to scooters with no human-powered drive mechanisms, the highest recorded speeds of bikes require enhanced levels of fitness and cycling experience. As such, the recorded speeds of bicycles may not reflect typical user speeds. Further testing with precise instruments such as accelerometers, a larger vehicle sample, and detailed motor and battery specifications would provide more accurate speed and performance data.

Table 6. Speed test results for e-scooters and e-bikes

Vehicle - Speed Test	Top Recorded Speed
Link (e-scooter)	15 mph
Veo (e-scooter)	15 mph
Lime (e-scooter)	16 mph
Spin (e-scooter)	17 mph
Veo Cosmo (sit down scooter)	16 mph
Bay Wheels Classic (non-motorized)	18 mph*
Bay Wheels ebike (motorized e-bike)	20 mph+*

*speed dependent on rider input (weight, strength)

Brake Test

To evaluate brake effectiveness on shared micromobility vehicles, we tested various brake styles and systems of each vehicle by measuring the stopping distance from top speed to a complete stop in a 200' zone. We marked lines every 5 feet along a straight path (Figure 10) and had a test rider accelerate to ~15 mph before applying both brakes at the 0-foot mark. The distance from the 0-foot mark to where the front wheel stopped was recorded with a tape measure. Each vehicle was tested three times.

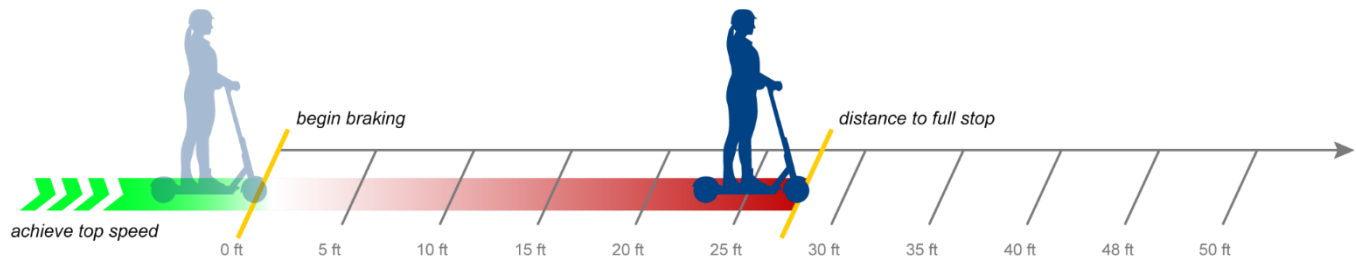


Figure 10. Visual overview of brake testing protocol done during field test experiment

Brake Test Results & Discussion

Braking distances varied from 9 to 30 feet across tested vehicles. Table 5 shows that scooters stopped within 9 to 16 feet from 15 mph, while non-motorized bicycles had similar braking distances. Motorized bicycles required nearly double the distance to stop. Added weight from motors and batteries, coupled with higher top speeds, likely contributes to their longer stopping distances. All vehicles except the e-bike, which used a disc brake on the front wheel, used only cable-actuated drum brakes. Maintenance issues like inadequate cable tension and compensations for brake pad wear also affect braking performance. Future studies should test a larger number of vehicles, evaluate individual brake performance, and use accelerometers to provide more detailed data on braking and deceleration profiles.

Table 7. Brake test results for e-scooters and e-bikes

Test Vehicle - Brake Test	Averaged Distance from Top Speed to Complete Stop
Link (e-scooter)	9 ft
Spin (e-scooter)	10 ft
Veo Astro 4 (e-scooter)	14 ft
Lime Gen 3 (e-scooter)	16 ft
Bay Wheels Classic (non-motorized)	11 ft
Veo Cosmo (sit down scooter)	15 ft
Bay Wheels e-bike (motorized e-bike)	30 ft

*(result is the average of 3 tests)

Vehicle Design Safety Recommendations

After documenting and test-riding nine vehicles in our study area, we noted design considerations that could positively contribute to rider safety.

Acceleration Curve

The rate of acceleration seemed to vary slightly between the different vehicles we tested. The experts we interviewed explained that it has become much easier for the shared micromobility providers to use GPS to customize and program the rate of acceleration and lower maximum speeds in busy pedestrian zones. Fast acceleration for new or less experienced riders can be a potential safety hazard as it can be startling or cause the operator to lose control of the vehicle. Conversely, the rate of acceleration needs to be fast enough to maintain balance after slowing for a turn. It could be recommended that first-time users have the option for a slower acceleration while they grow accustomed to using the vehicle. Lime scooters offer this as a feature in their app.

Handlebar height / Vehicle size / Rider size considerations

Shared bicycles generally have adjustable seat heights but fixed handlebar distances, making them suitable for riders between 5'2" and 6'3". This "one-size-fits-most" approach may be uncomfortable or unsafe for those outside this range. This is in contrast to privately owned bicycles, where a rider can purchase a bike with a frame sized for their body.

We reason that a very tall rider can more safely operate a device that is too small whereas a shorter rider experiences higher levels of risk when operating a vehicle that is too big. For example, shorter riders might find that even the lowest seat position prohibits comfortably reaching the ground, increasing the risk of tipping over. Scooters, with fixed handlebar heights and no seat height adjustments have limited capacity to accommodate different rider sizes as shown in Figure 11. This inability to customize fit can affect stability, confidence, and ultimately safety.



Figure 11. Example of 6' tall rider and 5' tall rider highlighting handlebar height, elbow position, and hand position on a SPIN e-scooter

Rider fit involves more than just vehicle size. Component design also plays a role. For example, consider the design of brake lever blades: lever length and shape, throw distance, and position must be designed and adjusted to fully activate the brake system without bottoming out on the handlebar. Small-handed riders may struggle to apply full braking power if the lever is not well-designed or maintained. Figure 12 illustrates how hand size affects lever actuation, emphasizing the need for regular maintenance and safety checks by fleet operators to ensure reliable operation.

Lighting Systems

While all the vehicles we studied featured integrated lighting systems, their locations, power sources, and light output varied. Scooters often have rear lights positioned close to the ground due to their small wheels and lack of a rear rack, making them less visible to drivers. Newer designs are adding lights to the handlebar, improving visibility with the added benefit of defining the device's width. While all devices have lighting systems that meet California vehicle code laws [VEH 21201(d)], not all are sufficiently bright for riders to navigate in dark conditions. Given the increased proportion of crashes occurring at night (Yang et al., 2020), additional lighting for better visibility is recommended. Future research should investigate micromobility lighting systems for more detailed recommendations.

Turn indicators

Veo scooters feature rear-facing blinking turn lights near the rear wheel. The Spin 6 scooter has additional forward-facing turn lights that are at each end of the handlebar which features auditory feedback to alert the rider when the turning lights are activated. Both systems are operated by a control on the handlebars. Integrated turning lights are safer for riders because they allow the rider to keep both hands on the steering controls while signaling as opposed to hand signaling. This is especially true for scooters as there are fewer points of contact between the rider and the vehicle compared to a bicycle where a rider utilizes the seat as a point of stability.



Figure 12. Photo demonstrating how large & small hands can reach a brake lever in its most relaxed position.

Wheel size

Larger wheel sizes on scooters provide greater rider stability due to the increased contact with the road and the more ground covered per rotation. Larger scooter wheels, such as the newer 10-inch diameter designs, enhance balance compared to earlier models with 7-inch wheels. They handle poor road conditions such as potholes and curbs much with greater stability as shown in Figure 13. However, because scooters have more physical limitations governing their design characteristics compared to bicycles, excessively large wheels could require impractically long wheelbases and larger overall scooter sizes to maintain a practical deck height from the ground.

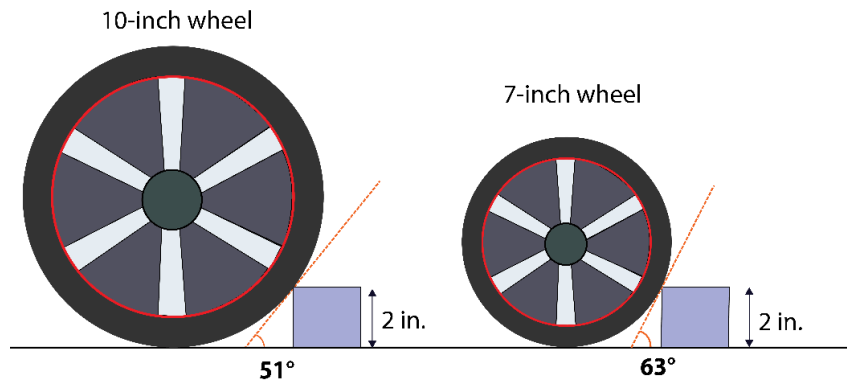


Figure 13. Visual explanation of wheel size vs. “angle of attack.” Larger wheels, with a smaller angle of attack, roll more easily over obstacles than smaller wheels do.

Brakes for Micromobility

Our stakeholder interviews revealed that drum brakes are lower maintenance, cheaper, and provide adequate stopping power. For shared micromobility fleets, disk brakes are less favorable because they are more prone to damage and more complicated to maintain. Figure 13 compares a covered drum brake against a disc brake system.

Drum Brakes

(Lime, Veo, Link, Lyft Bay Wheels Classic Bike)

- Reliable: fewer moving parts, less damage from street wear
- Cheaper and requires less maintenance

Cable-actuated Disk Brake

(Bird, Lyft Bay Wheels e-bike front wheel (back wheel is drum brake))

- Disks are more vulnerable to damage from impacts or misuse
- More complicated to adjust and maintain
- Have excellent stopping power



Figure 14. A) E-scooter drum brake vs. B) E-bike cable-actuated disk brake

Battery Safety

Motorizing bikes and scooters have contributed to their rapid growth, but batteries present several challenges related to safety, environmental impact, recycling, charging, and performance. Batteries are exposed to outdoor elements like moisture, vibration, high temperatures, and mistreatment (theft). Unfortunately, not all vehicles meet safety standards, resulting in fires, property damage, and injuries. Responsible micromobility operators establish charging systems to prevent lithium-ion battery overcharging and carefully monitor battery temperatures. It is crucial to avoid mismatched charging equipment and follow manufacturer recommendations to prevent damage. Best practices for battery maintenance include choosing UL-certified batteries, limiting the number of charge cycles, and unplugging the battery when fully charged. Battery care requires collaboration among operators, manufacturers, city managers, and users to reduce risk and educate



Figure 15. Battery in frame (left), swap out battery (middle), kiosk charging station (right)

the public about best practices. Figure 14 shows three different styles of micromobility batteries and their charging type. The left image shows a non-removable battery in a device that requires a van to collect and charge it at a warehouse. The middle image shows a swap out battery system that uses a rebalance team to replace the battery on the street. This system reduces the need to transport the scooter but increases risk of theft and damage from vibration. Right image shows a Lyft kiosk charging station in San Francisco featuring integrated e-bike charging that reduces expensive staff time but is more costly to connect the kiosk to the grid.

Shared Micromobility Service Cost

We documented the rental cost of each vehicle we tested (Table 9–Table 11). Table 9 shows the cost of each of the vehicles to unlock and ride per minute. These prices reflect the rental fee rates from March 2024 and can fluctuate depending on the vehicle service provider. A 15-minute ride on a shared e-scooter or e-bike ranges in price between \$5.80 and \$8.50, and the price for a 30-minute ride is \$9.60–\$12.49, depending on the vehicle model and operator. A few providers—Lime, Lyft Bay Wheels, and Spin—offer yearly memberships to reduce fees for regular users and reduced rates for lower income riders who apply and qualify for their limited pilot programs. In 2018, shared vehicle rides cost \$2 and were often subsidized by venture capital funding.

Table 8. Cost of shared micromobility vehicles reviewed in our study March 2024

Service Provider	Cost to unlock	Cost per minute	Cost for 15 min	Cost for 30 min
LINK e-scooter	\$1	\$0.39	\$6.85	\$12.70
Lyft e-bike	\$3.49	\$0.30	\$7.99	\$12.49
Lyft classic bike	\$3.49 (30min)	\$0.30 (after 30 min)	\$3.49	\$3.49
Lime e-scooter	\$1	\$0.50	\$8.50	\$15
Spin e-scooter	\$1	\$0.32	\$5.80	\$9.60
Veo e-scooter /moped	\$1	\$0.35	\$6.25	\$11.50

Table 9. Lyft Bay Wheels membership is \$199 / year in 3/2024

Service Provider	Cost to unlock	Cost per minute	Cost for 15 min	Cost for 30 min
Lyft classic bike	free	\$0.20 (after 45 min)	free	free
Lyft e-bike	free	\$0.15	\$2.25	\$4.50

Table 10. Spin at the University of California Davis fees

Service Provider	Cost to unlock	Cost per minute	Cost for 15 min	Cost for 30 min
Spin e-scooter	\$1	.32	\$5.80	\$10.60
Spin e-bike	\$1	.32	\$5.80	\$10.60
Spin Access	.50	.10	\$2.00	\$3.50

* Source for Table 9–Table 11: <https://taps.ucdavis.edu/spin>

Limitations

Our research provides valuable insights into micromobility safety, yet several limitations exist. First, the dynamic nature of micromobility service providers posed a challenge to this study, because companies come and go, affecting the availability, maintenance, and quality of the vehicles in the San Francisco Bay Area. Second, our testing did not account for nighttime-riding, rain, or poor street conditions, which are critical factors in real world use. Third, we missed the opportunity to directly interview riders, limiting our understanding of rider confidence, ability, and size challenges when navigating obstacles such as potholes and curbs.

Conclusion

Shared micromobility services, vehicle designs, regulations, street facilities, and user behavior will continue to evolve as business models and safety measures advance. Micromobility, whether electric, shared, or personal, holds significant potential for facilitating first- and last-mile connections with public transit. This research has examined shared micromobility vehicle design features in the San Francisco Bay Area, documenting trends and changes from 2017-2024. We highlighted successes and challenges and provided recommendations for safer rider behavior, vehicle design considerations, and environmental improvements. Consistent design standards for battery charging, braking, and sizing are needed. Further research and design solutions focused on improving roads and charging infrastructure present opportunities for collaboration among city managers, fleet operators, and vehicle designers. Micromobility remains a low-carbon transportation option helping reduce vehicle emissions.

We recommend that cities increase protected bike lanes, offer e-bike riding lessons, promote helmet use, emphasize sobriety while riding, and enhance vehicle security against theft. Additionally, cities should work with micromobility operators to implement battery safety protocols, improve road conditions, enhance lighting, and consider larger wheels for e-scooters (10") with shocks.

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