

FACILITATING MICROMOBILITY FOR FIRST AND LAST MILE CONNECTION WITH PUBLIC TRANSIT THROUGH ENVIRONMENTAL DESIGN: A CASE STUDY OF CALIFORNIA BAY AREA RAPID TRANSIT STATIONS

**Ferguson, Beth;
Sanguinetti, Angela**

University of California, Davis

ABSTRACT

Micromobility has the potential to reduce greenhouse gas emissions, traffic congestion, and air pollution, particularly when replacing private vehicle use in conjunction with public transit for first- and last-mile travel. The design of the built environment in and around public transit stations plays a key role in the integration of public transit and micromobility. This research presents a case study of rail stations in the California Bay Area, which are in the operation zone of seven shared micromobility operators. Nineteen stations and their surroundings were surveyed to inventory design features that could enable or constrain use of micromobility for first- and last-mile access. Shared mobility service characteristics, crime records, and connections to underserved communities were also documented. Key design solutions were identified based on the findings, including protected bike lanes, increased shared bike and scooter fleet size and service area, and clear signage indicating parking corral and docking points.

Keywords: Micromobility, Urban Design, Societal consequences, Social responsibility, Ecodesign

Contact:

Ferguson, Beth
University of California, Davis
Design
United States of America
bferguson@ucdavis.edu

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1 INTRODUCTION

Industry stakeholders, policy-makers, and academicians are imagining a more sustainable transportation system where shared micromobility and public transit supplant private car ownership as the dominant mode (Shaheen and Cohen, 2018). Shared micromobility services (e.g., on-demand, docked and dockless bikes and light electric vehicles) are rapidly proliferating, but public transit use in the US has decreased (Mallett, 2018) and faces further challenges due to the COVID-19 pandemic. Shared micromobility can facilitate public transit by providing options for first-and-last-mile connections, extending the catchment area around stations, and bridging gaps in the transit network (Shaheen and Chan, 2016). The potential for micromobility connectivity with public transit depends on a variety of factors (e.g., accessibility and safety), many of which relate to environmental design at and near transit stations.

Built environment features that promote micromobility and transit connectivity include secure networks of active travel paths as well as safe and attractive mixed-use neighborhoods with convenient access to affordable public transit (Giles-Corti et al., 2016; Zhao, 2014). For docked shared micromobility services in particular, important features include proximity of docking stations to work and home along with dense vehicle availability in multiple nearby locations to create a network (Bachand-Marleau and Lee, 2012; Shaheen et al., 2011). Protected infrastructure and lower street speed limits are associated with reduced illegal use of e-scooters on sidewalks (Portland Bureau of Transportation, 2018).

This paper presents a case study of Bay Area Rapid Transit (BART) heavy rail stations in the California Bay Area. Stations were surveyed to inventory design features in and around the stations that might facilitate or hinder the use of personal, rented, or leased bikes, e-bikes, and e-scooters for first-and-last-mile connections. Results highlight best practices, research gaps, and opportunities for improvement that can generalize to other types of transit stations and locations.

1.1 The Bay Area and BART

The California Bay Area was selected as the focus of this case study because it is a region with both relatively high public transit and shared micromobility use as well as high rates of using micromobility for trips to and from transit. As such, it is a potential testbed for innovative and adaptive transit station design features that support micromobility. Bay Area Rapid Transit (BART) began operation in 1972 as a heavy rail elevated and subway system designed to connect suburbs with urban centers, like San Francisco and Silicon Valley. BART has 50 stations that cover 131 miles across 5 counties and in 2019 averaged 118 million annual passengers.

2 METHODOLOGY

A subset of 19 BART stations were selected in order to focus on those with relatively greater opportunities for use of shared micromobility. Available shared micromobility services vary throughout the region, as companies must apply for fleet use permits from each city and regulators manage permit agreements, rules, and operator exclusivity differently with each provider. Four cities with BART stations in the Bay Area currently have agreements with shared micromobility providers: Berkeley, Oakland, San Francisco, and San Jose. The 19 BART stations in these cities were the focus of this study.

Data were collected between July 2020 and April 2021 to describe the stations as well as the surrounding area within a one-mile radius, which can be considered the catchment area for first-and-last-mile travel origins and destinations. Features that past research suggests facilitate micromobility were inventoried at each station, including level of protection and connectivity of bike lanes surrounding the station; service vehicle density; micromobility parking facilities; station safety (crime rates); and features contributing to the attractiveness of the station and surrounding area (plants and outdoor seating at the stations, and nearby cafes). Data were also gathered on other relevant features, including micromobility parking affordances and signage, since signage to support way finding is a critical aspect of user experience at transit hubs (Farr et al., 2012). Data were gathered and triangulated from a variety of sources, including site visits to each of the 19 stations, Google Maps, BART and Bay Area Department of Transportation websites, city websites and shared micromobility

service apps. Table 1 provides the codebook for data collection which includes definitions and levels of the variables assessed and data sources.

Table: 1 BART Station Survey CODEBOOK

Shared Micromobility Service Availability			
Feature	Definition	Codes	Data Sources
Shared micromobility service provider	Station in service provider operating area	Lyft Bay Wheels	baywheels.com/map
		Spin	spin.app
		LINK	link.city
		Veoride	veoride.com
		Lime	li.me
		Scoot	scoot.co
		Revel	gorevel.com
Bay Wheels dock density	Total number of bike spots (open or filled) at the Bay Wheels docking station at the BART station	Count	baywheels.com/map
Nearby Bay Wheels docking stations	Other nearby Bay Wheels docking stations for picking up/dropping off shared bikes and e-bikes within 1-mile radius of BART station	Count	baywheels.com/map
Micromobility Parking and Storage			
Feature	Definition	Codes	Data Sources
E-scooter corral	Demarcated areas for dropping off shared dockless e-scooters and e-bikes adjacent to BART station	Count	Site observation
Outdoor bike racks	Number of outdoor bike racks for parking private and shared dockless bikes and scooters	Count	Site observation bart.gov/guide/bikes
Indoor bike racks	Number of indoor bike racks for parking private bikes and scooters	Count of each: BIKEEP, indoor racks	Site observation bart.gov/guide/bikes
24-hour bike station	Number of parking spots in BikeLink 24-hour card-secure parking rooms within 1 block of station	Count	Site observation bikehub.com/bart/
Bike lockers	Digital bike lockers for bike and gear managed by BikeLink card	Count	Site observation bikelink.org
Valet bike parking	Number of parking spots for 7am-7pm BikeHub valet parking service	Count	Site observation bikehub.com/bart/
Other Supportive Station Design			
Feature	Definition	Codes	Data Sources
Signage	Content of maps and signs around station	Shared micromobility signage	Site observation
		[pictures and descriptions of other content]	
Charging facilities	Presence of charging stations for personal e-bikes and e-scooters	Yes or No	Site observation
Bike repair facilities	Self-service stand with tools for DIY repairs or BikeHub shop with repair service staff	BikeHub shop	Site observation
		Self-service	bikehub.com/bart/
Multilevel access	Accommodations for multilevel station access for bikes and scooters	Escalator	Site observation
		Elevator	
		Stairs with bike channel	bart.gov/guide/bikes
		Stairs without bike channel	
Accessible fare gates	Wider fare gates to accommodate personal vehicles (bikes, e-scooters, wheelchairs, stroller)	Count	Site observation
Station Attractiveness			
Feature	Definition	Codes	Data Sources
Outdoor seating	Presence of any seating outside the station	Yes or No	Site observation
Cafes	Presence of cafe at station or within 1-2 blocks	Yes or No	Site observation yelp.com
Plants	Presence and type of plants	Trees	Site observation google.com/earth
		Shrubs	
		Flowers	
		Empty planter	
		Nothing	
Crime incidents in 2019	Police reported crimes at BART stations during 2019 (time period selected to describe stations prior to the COVID-19 pandemic)	Count	bartcrimes.com

Supportive Street Facilities			
Feature	Definition	Codes	Data Sources
Car lane (only)	Least supportive of micromobility	Yes or No	Site observation google.com/maps with bicycling filter
Bike boulevard (Class 3)	Street lane shared by bikes, buses, and cars (25 mph limit); better than car-only but can be dangerous	Yes or No	Site observation google.com/maps with bicycling filter
Bike lane (Class 4)	Portion of road designated by striping for bike	Yes or No	Site observation google.com/maps with bicycling filter
Protected cycle track (Class 2)	Bikeway at street level with physical protection	Yes or No	Site observation google.com/maps with bicycling filter
Greenway bike path (Class 1)	Bike path with no cars	Yes or No	Site observation google.com/maps with bicycling filter
Slow street	Streets closed to through traffic for during COVID19	Count	google.com/maps

Other Multimodal Affordances			
Feature	Definition	Codes	Data Sources
TNC zone	Presence of a designated zone (signage) for TNC dropoff/pickup	Yes and No	Site observation
Bus connection	Bus stop adjacent to BART station	Yes or No	Site observation
Car parking	Number of parking spots at BART station lots	Count	Site observation
Car share	Parking spots marked for Zip Car or Gig Car at East Bay BART stations or within 3-4 blocks of SF BART stations	Count	Site observation
Motorcycle parking	Number of parking spots at BART station lots	Count	Site observation

3 RESULTS AND DISCUSSION

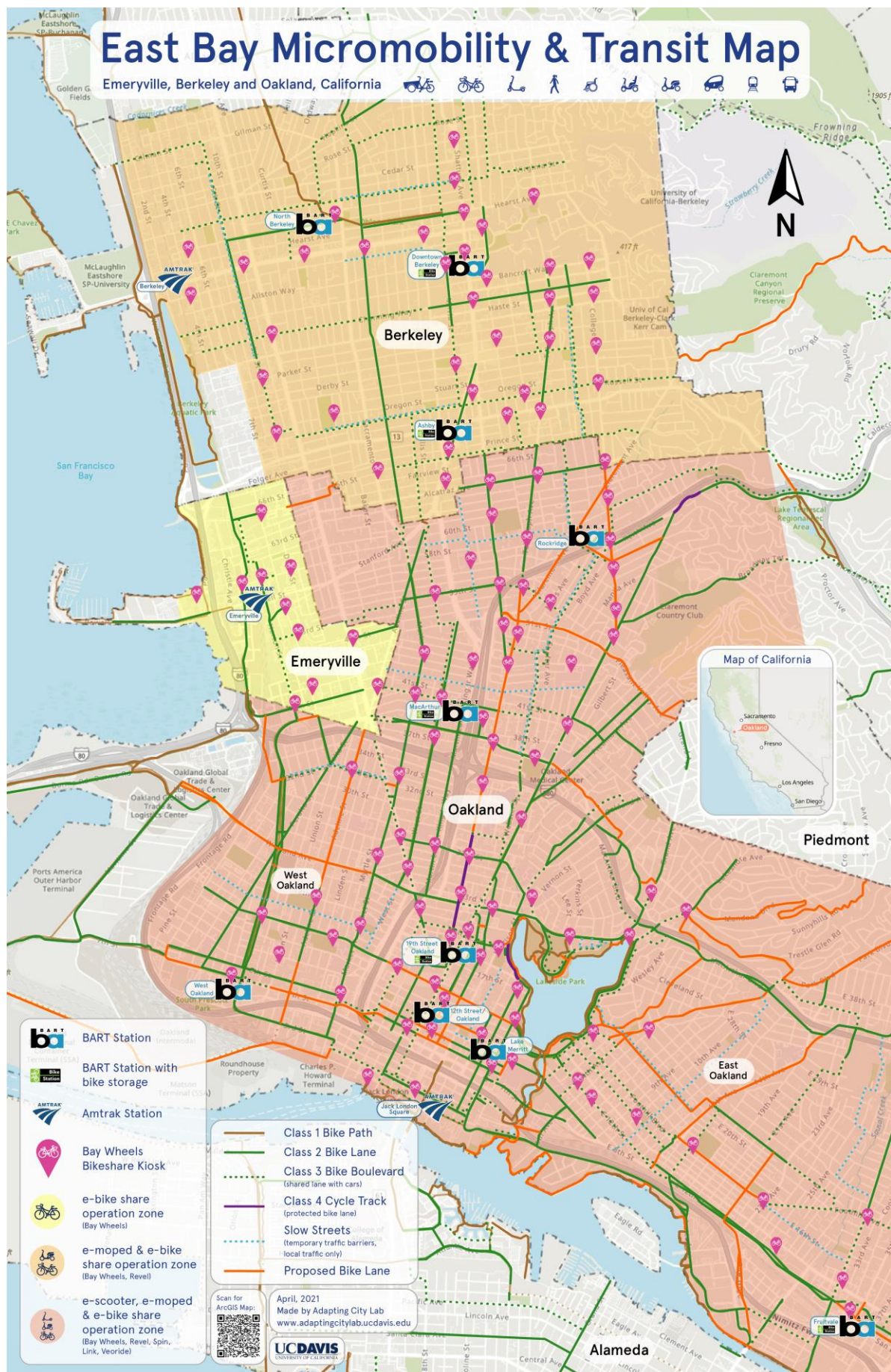
Results are organized into the categories developed for the station feature design codebook and presented along with interpretations regarding implications for micromobility and transit connectivity.

3.1 Shared micromobility service availability

There is a high turnover rate of permitted micromobility companies, with several operators coming and going during the period over which this research was conducted. As of April 2021, seven operators have permitted fleets operating in at least 1 of the 19 stations (Table 2). Bay Wheels, a docked bike and scooter service co-managed by Lyft and two local government agencies, operates at all the stations surveyed. Bay Wheels has over 2,600 bicycles and 262 stations, including kiosks at BART stations. The other six operators have dockless vehicle services. Figure 1 maps the service boundaries of each operator along with BART stations and bike lanes.

Table 2. Shared micromobility services by city as of April 2021

		City			
		San Francisco (BART Station: Embarcadero, Montgomery, Powell, Civic Center, 16th, 24th, Glen Park, Balboa Park)	Berkeley (BART Station: N. Berkeley, Downtown Berkeley, Ashby)	Oakland (BART Stations: Rockridge, MacArthur, W. Oakland, 19th, 12th, Lake Merritt, Fruitvale)	San Jose (BART Stations: Berryessa/North)
Shared Micromobility Operator	Bay Wheels (bike, e-bike, e-scooter)	Yes	Yes	Yes	Yes
	Spin (e-scooter)	Yes	No	Yes	No
	LINK (e-scooter)	No	No	Yes	Yes
	VeoRide (e-scooter)	No	No	Yes	No
	Lime (e-scooter, e-bike)	Yes	No	No	Yes
	Scoot (e-scooter, e-moped)	Yes	No	No	No
	Revel (e-moped)	Yes	Yes	Yes	No
	Total Permitted Operators	5	2	5	3
	Source	www.sfmata.com	www.cityofberkeley.info	www.oaklandca.gov	www.sanjoseca.gov



Consistency of operators across cities, as with Bay Wheels, may create a seamless experience. For example, a user could take a Bay Wheels bike from a dock near their home to a Berkeley BART station and then pick up another at an Oakland station to take to work. In contrast, the multiple dockless micromobility fleets are not consistently available across Bay Area cities. This creates complexity that could inhibit adoption because each service has its own app, vehicle types, and rules with which users must become familiar. The high turnover of operators and changing service agreements from year-to-year is also problematic; users must adapt when their preferred operators reduce or remove their fleets.

Bay Wheels kiosks at these BART stations have an average of 27 docks (SD = 6). The number of Bay Wheels docking stations in the surrounding neighborhood (1-mile radius) vary considerably (Mdn = 15; min-max: 2-57). As [Shaheen et al. \(2011\)](#) noted, a high density of vehicles at multiple locations is needed to create a network effect. BART stations with fewer nearby Bay Wheels stations are thus less conducive to last-mile access for users who live or work further from the BART station and other Bay Wheels docks.

3.2 Micromobility parking and storage

Parking corrals are an analogous facility to docking stations for shared dockless e-scooters and e-bikes, providing designated parking and reliable access. Corrals were present at only two stations (Figures 2-3). In the absence of corrals, shared dockless vehicle users are left without direction as to where to locate or drop off a vehicle (Figure 4). Oakland recently started requiring that all e-bikes and e-scooters be locked to a bike rack or street sign when parked (Figure 3). This prevents the vehicles from blocking a sidewalk but creates the need for more bike racks to have room for both private and shared bikes and scooters.

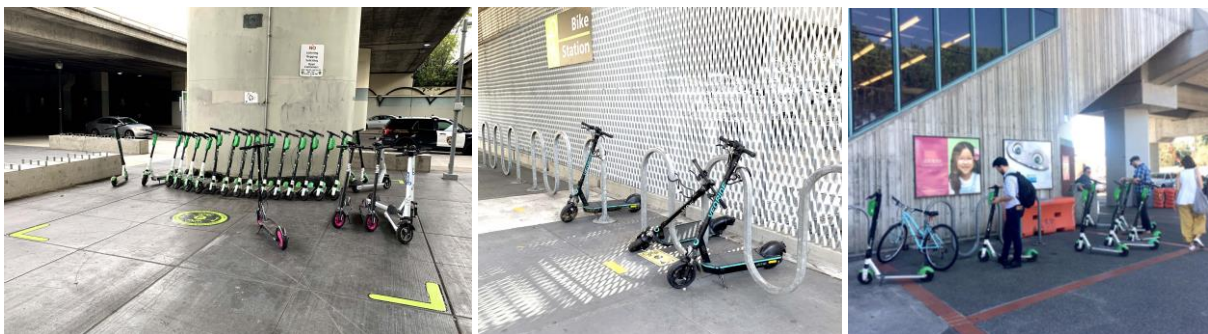


Figure 2. MacArthur BART station e-scooter corral parking

Figure 3. MacArthur BART station e-scooter lockable bike rack corral

Figure 4. W. Oakland BART station with e-scooter blocking racks in the absence of a corral

The presence and capacity of indoor and outdoor bike racks and secure private bike storage ranged widely across stations (Table 3). They were particularly limited at San Francisco stations, which are underground, and the above-ground space is limited in this high-density urban area. Outdoor racks are particularly important for facilitating shared micromobility because, unlike indoor racks and storage, they can be used to park dockless e-bikes and e-scooters (Figure 5). In the absence of outdoor racks, shared dockless e-bike users are left without direction as to where to reliably collect or drop off their vehicle (Figure 6).

Table 3. Micromobility parking and storage facilities at BART stations

	East Bay & San Jose	San Francisco	All Stations
E-scooter corral	Present at 2 stations	Present at 0 stations	Present at 2 stations
Outdoor racks	Mdn = 28; min-max: 2-169	Mdn = 3; min-max: 0-12	Mdn = 12; min-max: 0- 169
Indoor racks	Mdn = 14; min-max: 0-60	Mdn = 0; min-max: 0-45	Mdn = 0; min-max: 0-60
Secure storage	Mdn = 154; min-max: 12-383	Mdn = 6; min-max: 100	Mdn = 96; min-max: 0-383

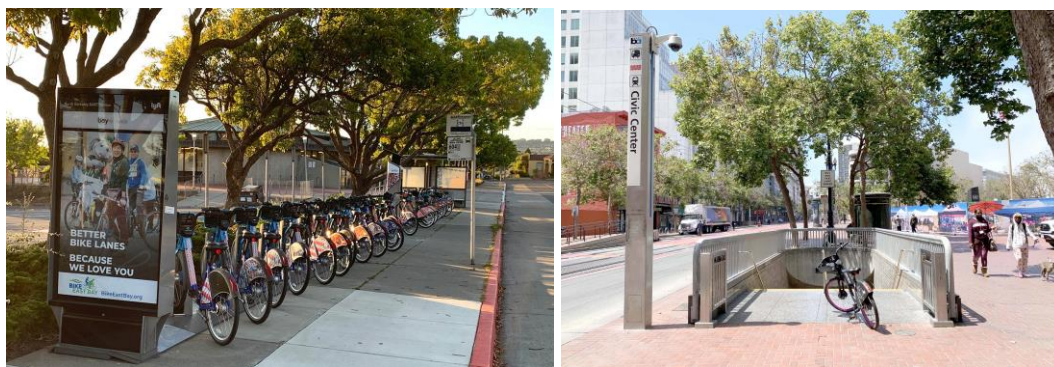


Figure 5. North Berkeley BART bay wheels bike share kiosk

Figure 6. Bay wheels e-bike parked at the top of the civic center BART station stairs

3.3 Other micromobility-supportive station design features

Other micromobility-supportive station features include signage, e-bike and e-scooter charging stations, bike repair services, and multilevel access and fare gate affordances for riders traveling with private bikes or scooters. Shared micromobility signage was only observed at the two stations with corrals (Figure 7), indicating where users should drop off their scooters and bikes. Signage for bus schedules and maps of stations and surrounds were prevalent, but none included place markers for Bay Wheels docking stations or corrals (e.g., Figure 8).



Figure 7. BART dockless scooter & bike parking sticker marking parking corral

Figure 8. Map of transit stops around the MacArthur BART station that does not show bay wheel kiosk or the parking corral for shared dockless e-scooter and e-bikes

Only one station currently provides charging facilities for private e-bikes and e-scooters, though there are plans for charging to be included at the Downtown Berkeley station's new valet bike parking service. Several East Bay stations but none in San Francisco provide bike repair services.

BART riders traveling with a bike or stand-up scooter are instructed (via signage) to use the elevator or stairs to reach the train platforms at underground or multilevel stations. All stations have an elevator and stairs; however, these facilities are not always convenient, easy to locate, or safe. Bikes and scooters are not allowed on escalators, which are also present at every station; escalators are generally more convenient, easy to locate, and safe. Despite policy, riders were observed with bikes and scooters on escalators. BART stations have started the process of installing the first bike wheel channel alongside the stairs at the 16th Street BART station, so riders do not have to carry their vehicle up and down. All BART stations also have at least one accessible fare gate for bikes, wheelchairs, bags, and baby strollers.

3.4 Micromobility-supportive street facilities

Data were collected on the presence of different types of street facilities (i.e., bike lanes) that serve bikes, e-bikes, and e-scooters within a four-block radius of each BART station (i.e., the most station-adjacent part of a travelers' first-and-last-mile journeys). Figure 9 depicts the main types of bike lanes defined by the US National Association of City Transportation Officials (NACTO). Figure 1, created

with ArcGIS and the Google Maps bike lane filter, illustrates the distribution of these different types of street facilities.

All stations had at least some nearby street segment without any type of bike lane. Most stations had nearby Class 2 classic bike lanes (84%) and/or Class 3 bike boulevards (shared with cars; 84%). Class 1 separated bike paths and Class 4 protected cycle tracks, which are safer and more comfortable facilities, were found near 37% and 16% of stations, respectively (Figure 10). There was a lack of consistency in the bike lane networks noted, including intermittent Class 2 bike lanes and Class 3 bike boulevard on the same route, bike lanes that stop altogether from block-to-block, and absence of bike lanes in streets directly adjacent to stations. Notably, there were slow streets near 58% of stations. Slow streets have been implemented in many cities in response to the COVID-19 pandemic (including San Francisco and Oakland); a segment of street is closed to through traffic in order to support walking and biking.



Figure 9. Bike lane classification. B. Ferguson, J. Wattimena, 2021 (data source: NACTO)

Figure 10. Short segment of protected Class 4 cycle track on telegraph ave. Oakland, CA

3.5 Station attractiveness

Safe and attractive neighborhoods surrounding public transit stations are important to support active transportation and micromobility (Giles-Corti et al., 2016). Features that may contribute to attractiveness include outdoor seating and shade trees at stations and nearby cafes. All East Bay stations (and the new San Jose station) had outdoor seating, whereas no San Francisco BART stations did; again, this is likely due to limited above-ground space near the stations in dense urban areas. Cafes were found within 1-2 blocks of all but four stations. Greenery (specifically, trees) were observed at 63% of stations; there were empty planter boxes at two stations. Crime incidents at the stations in 2019 ranged from 7 to 108 (Mdn = 30; n = 18); Berryessa BART station was excluded from this analysis since it just opened in June 2020. The high crime rate at some stations could certainly be a deterrent to use of the station and BART in general, as well as use of micromobility for first-and last-mile connections.

3.6 Other multimodal affordances

Designated ride-hailing loading zones have implications for micromobility safety because, in their absence, ride-hailing drivers may be interfacing with bike and scooter riders at the curbs around the station. Only 37% of the BART stations surveyed had marked ride-hailing zones, although TNCs (Transportation Network Companies) are not allowed along Market Street in San Francisco. All stations had bus connections, 47% had car-share parking (i.e., Zipcar, GIG Car Share), 42% had car parking, and 21% had motorcycle parking. Similar to micromobility parking, car parking was much less prevalent at the denser, urban stations in San Francisco. We believe multimodal transportation options like car share and TNCs support micromobility and public transportation users to live car free while still being able to use a shared car when transporting large cargo or taking long trips.

4 CONCLUSION

This research inventoried transit station design features with implications for micromobility at a subset of California Bay Area Rapid Transit (BART) heavy rail stations. This case study should reveal exemplary practices in designing for the integration of shared micromobility and public transit since it is a region where both services are heavily used relative to most other parts of the US. While many innovative features were documented, the findings also highlight areas for improvement.

Due to inconsistent availability of micromobility operators throughout the region, users may have to learn to navigate multiple service apps, use different vehicle types, and remember different rules. Stations lacked adequate parking facilities, particularly for dockless vehicles, and associated signage. Users must actively look for micromobility at transit stations or nearby streets. Stations need to prioritize corrals with racks to increase reliability and ease of use of shared micromobility services; it also helps to maintain order and protect pedestrian safety from trip hazards. Transit stations should update their printed maps and websites to highlight shared micromobility docking stations at and around the station, dockless vehicle parking zones, and recommended routes for bikes and e-scooters.

Results indicated a lack of safe street facilities for bikes and scooters around transit stations. For optimal facilitation of micromobility and transit connectivity, cities and public transit agencies should work together to implement networks of protected bike lanes within a two-to-five-mile radius of transit stations. Bike lane investments and marked wayfinding around stations will improve safety and popularity for shared micromobility and cycling in general.

Many of the design principles discussed here will be beneficial to global cities managing public transit and micromobility. Micromobility stands to become an important part of public transportation, solving for the problem of first-and-last-mile connectivity and providing an alternative or complementary option for public transit users in the wake of the COVID-19 pandemic. Future research should solicit feedback from shared micromobility and transit users on their preferred station design features and attempt to quantify the influence of station design features on shared micromobility use for first-and-last-mile travel.

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