A GIS-Based Strategy for Expanding Austin's Bikeshare Network

Danny A. Xie
Undergraduate Research Assistant
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
dannyxie@utexas.edu

Kara M. Kockelman, Ph.D., P.E.
(Corresponding Author)
Dewitt Greer Professor in Engineering
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
kkockelm@mail.utexas.edu

Emre Yucel, Ph.D.
(Corresponding Author)
McCombs School of Business
The University of Texas at Austin
emre.yucel@utexas.edu

Accepted for presentation at 105th annual meeting of *Transportation Research Board*.

ABSTRACT

Austin, Texas faces increasing challenges related to traffic congestion and equitable access to transportation. This thesis investigates the potential for expanding the CapMetro Bikeshare system to address these issues by utilizing the POLARIS Transportation System Simulation Tool to project future demand for bikeshare services across the city, considering various travel modes (automobile, walk, and bike) and land-use characteristics. A station placement algorithm is developed and applied to prioritize zones for expansion. This algorithm employs a weighted score index, integrating variables related to demand potential, land-use characteristics, transit connectivity, and equity to identify suitable locations. The results of the algorithm propose a significant expansion of the service zone, growing the zonal service area by 940%. The expansion plan adds 1,902 bikeshare station docks and 951 e-bikes through a phased approach that prioritizes both strengthening the core network and expanding into underserved communities. While the expansion greatly benefits the city through boosting multi-modal connectivity and offering potential alternatives to car dependency, the operational sustainability of this largely grant-funded expansion necessitates financial strategies extending beyond user fares for long-term viability. Beyond offering a GIS-based solution, solutions and initiatives are proposed to promote equitable ridership.

Keywords: Bikeshare, Bike Station, Location allocation, POLARIS, GIS

INTRODUCTION

Bikeshare programs have expanded and developed rapidly over time, with the global bikeshare fleet now comprising 4.5 million bikes operating in over 1,500 cities (Fishman & Allan, 2019). In the modern day, new technologies allow bike rentals easily and inexpensively–mobile apps allow bikeshare users to check real-time inventories and computerized docking stations with automatic locking mechanisms and financial commitment to prevent vandalism and theft (Shaheen et al., 2011; Campbell, 2024). More recently, electric bikes (e-bikes) have been integrated into many bikeshare systems (Li et al., 2024). Compared to classic bicycles, e-bikes allow quicker acceleration and higher top speeds without the tradeoff of increased fatigue and physical strain. E-bikes are particularly helpful for those who find traditional biking challenging due to physical fitness levels or hilly terrains.

Bikeshare's flexibility enables multi-modal integration, crucially addressing the first/last mile problem (the poor connection between trip origins or destination and public transit stations) by bridging connectivity gaps between origins/destinations and transit stations (Lu et al., 2021; Fishman et al., 2013; Parkes et al., 2013; Kåresdotter et al., 2022). Facilitating one-way trips to and from transport hubs, bikeshare effectively "softens" the rigid fixed-route transit and expands its functional area beyond walking distance. This synergy, potentially enabling up to 50% of rail trips to start by bike as demonstrated in the Netherlands, makes transit more viable for more people (Fishman et al., 2015a).

Beyond enhancing transit connectivity, bikeshare offers various benefits to users and contributes positively to the urban environment. The rise of e-bikes within bikeshare systems provides moderate-intensity physical activity–higher than walking but lower than conventional cycling–and can measurably improve cardiorespiratory fitness, especially for previously inactive individuals (Bourne et al., 2018). This contributes to public health goals, although the net benefit can be slightly offset if cycling replaces walking trips (Fishman et al., 2015a). Bikesharing reduces travel time and costs and lowers the barrier to urban cycling (Ricci, 2015). These effects are seen through an increase in bikeshare trips for commuting, economic, social, and leisure activity purposes (Ricci, 2015). These impacts are not only observed by bikeshare users however; bikeshare trips increase the visibility of bicycles on streets and help normalize the image of cyclists in everyday attire (Fishman et al., 2013; Goodman & Cheshire, 2014; Murphy & Usher, 2012).

Case Study of Austin's Bikeshare Service

Austin faces significant traffic congestion (ranking 21st in the U.S.) and associated costs, largely driven by a high reliance on single-occupancy vehicles (66% of work commutes in 2021) despite moderate public transportation access (Inrix, 2024; City of Austin, n.d.-a). To address this, the Austin Strategic Mobility Plan aims for a 50/50 mode split between single-occupancy vehicles and alternatives (walking, transit, biking) with an emphasis on equitable mobility access. Within its mobility goals, the city has focused on cycling through initiatives like the Austin Bicycle Plan 2023. This plan draws from the All Ages and Abilities Bicycle Priority Network and ATX Walk Bike Roll to reshape the built environment with safer, better connected infrastructure (e.g., protected bike lanes, trails) that integrates with transit to make mobility more affordable and equitable (City of Austin, n.d.-b; City of Austin, 2019). These improvements support Austin's long-term vision outlined by Imagine Austin for a more compact, connected, healthier, and less car-dependent city, particularly benefiting lower-income households through cycling's potential for cost savings (City of Austin, 2012; Lipman, 2006). The plan emphasizes integration with bus routes and Austin's developing high-capacity transit lines (alongside projects like the I-35 Capital Express Central expansion), creating first and last mile solutions by expanding transit's reach far beyond a traditional walking radius–potentially increasing the ½ radius to 1.5-2 miles.

Despite Austin's ambition to develop a bike-friendly landscape, current transportation patterns remain heavily skewed towards automobiles, with only 1% of commuters cycling to work. This indicates a need to improve not just infrastructure but also convenient bicycle access, a need Austin's existing bikeshare system can help meet.

Austin's bikeshare system initially launched as B-Cycle in 2013 with limited scale primarily focused in the downtown core and University of Texas campus (CapMetro, 2024a). The system transitioned to the CapMetro operated Metrobike in 2020 featuring electric bikes (e-bikes) (CapMetro, 2021). Rebranded as CapMetro Bikeshare in July 2024, the system is now undergoing a major expansion funded by $11.3M through TxDOT (CapMetro, 2024b). The project involves replacing existing bikes and stations to a fully electric fleet with more than 300 stations and 3,000 bikes over ten years (CapMetro, 2024b). CapMetro also aims to integrate Bikeshare with transit connections and develop equitable expansion into historically underserved communities (CapMetro, 2024a). User feedback reveals demand for more stations and reliable e-bike availability, while citing inadequate infrastructure as a primary barrier for non-users.

The expansion operates under a City-CapMetro partnership with the City of Austin as owner of all physical assets (stations and bikes) while CapMetro manages operations, funded by fares, advertising, and city contributions. Municipal ownership limits service to Austin's city limits. Capital costs are largely grant-dependent, allowing placement decisions to prioritize ridership, connectivity, and equity over station cost (Simpson, personal communication, 2024). However, operational challenges include balancing cost-efficiency with service continuity during system expansion, transitioning dock-charging stations, and scaling rebalancing costs and logistics (Simpson, personal communication, 2024).

While bikeshare systems hold promise for enhancing urban mobility, effective implementation faces challenges including suboptimal station placement, inequitable access that fails to serve diverse and underserved communities, and a misalignment with true demand patterns, leading to overconcentration in downtown cores or affluent areas (Chardon et al., 2017; Shaheen et al., 2010). These issues frame the central problem addressed by this study: developing a data-driven, equitable, and efficient methodology to guide the expansion of Austin's currently limited and geographically concentrated CapMetro Bikeshare system and ensure that the planned investment meets city-wide mobility needs and integrates with other transport modes. This study analyzes the historical bikeshare trip data and spatial distribution of current bikeshare stations within Austin and leverages the POLARIS Transportation System Simulation Tool to model latent bikeshare demand using short auto, bicycle, and pedestrian trips. A weighted scoring system is developed incorporating demand potential, land-use, transit connectivity, and equity factors derived from literature and CapMetro goals. Using a station placement algorithm a bikeshare station expansion strategy will be proposed. The study offers direct, actionable insights to inform CapMetro's ongoing $11.3 million bikeshare expansion project and support the City of Austin's mobility, equity, and public health goals.

LITERATURE REVIEW

Land-Use Characteristics

Land-use diversity significantly influences bikeshare system utilization patterns. Research consistently demonstrates that neighborhoods with mixed land uses–combining residential, commercial, recreational, and institutional uses–generate higher bikeshare ridership (Noland et al., 2016; Zhang et al., 2017). This aligns with Vandenbulcke et al.'s (2011) finding that compact cities with diverse land uses support cycling by creating shorter, more direct trips. Notably, areas lacking land-use diversity often necessitate longer trips to access desired services, a pattern observed in both autonomous vehicle adoption studies (Nodjomian & Kockelman, 2019) and bikeshare contexts (Buck & Buehler, 2012).

Various components of mixed-use environments–particularly educational institutions, employment centers, and commercial/recreational facilities–each demonstrate strong individual associations with bikeshare demand. Universities, schools, and high employment density correlate with weekday commuter demand for bikeshare ridership (Croci & Rossi, 2014; He et al., 2019; Guidon et al., 2020; Hampshire and Marla, 2012). This weekday commuting demand pattern reflects the function of bikeshare systems in connecting residential neighborhoods with employment centers (Faghih-Imani et al., 2014; Faghih-Imani et al., 2017).

While work and school trips dominate weekday ridership, recreational and entertainment-related trips form a substantial secondary demand segment, spiking on weekends and weekday evenings (Lin et al., 2019; Faghih-Imani et al., 2014). Recreational destinations include bars and restaurants, shops, cultural attractions, museums, and entertainment venues (Kabak et al., 2018; Guidon et al., 2020; MacArthur et al., 2018). Public parks in particular drive bikeshare demand as cyclists may travel through the park due to the lower accident risk and absence of traffic compared to major roadways (Guo and He, 2020; Vandenbulcke et al., 2011), suggesting that park-adjacent station placement may enhance both safety and accessibility.

Urban Infrastructure

Bikeshare systems rarely operate in isolation and their value is maximized when they enhance overall destination accessibility by enabling multi-modal journeys and ideally facilitating shifts away from less sustainable or efficient modes. Close proximity between bikeshare stations and public transit stops generally correlated with higher ridership for both modes (Hampshire & Marla, 2012; Martens, 2004; Martens, 2007); however, the benefits of this synergy is distance-sensitive. Research indicates that bikeshare produces the most significant impact on reducing auto-dependence (around 10%) when the connection to mass transit is less than 0.6 miles, with benefits extending up to 1 mile (Basu & Ferreira, 2021). If the distance between the origin or destination and transit stop are less than 0.3 miles, ridership decreases, as walking becomes a more convenient option (Basu & Ferreira, 2021). Integrating bikeshare with transit can significantly reduce the need for private vehicles to access stations (Martin & Shaheen, 2014) and contributes to higher overall bikeshare usage, as seen in many European and North American cities (Goodman & Cheshire, 2014; Shaheen et al., 2014).

Street measurements and intersection density also influence bikeshare usage patterns. Mix et al. (2022) found that a greater number of intersections and longer streets positively affect trip generation in Santiago, Chile, indicating a higher street network density is associated with more bikeshare trips which is consistent with findings regarding land-use variables. However, the relationship between intersection density and bikeshare preference appears nuanced. A study conducted in Xi'an, China found that intersection densities below $65/km^2$ negatively affect shared bike choice, while densities above this threshold had positive effects (Ji et al., 2024). This study also found that bikeshare users preferred networks with more direct connections as opposed to more reliance on major arterial roadways. This preference for more interconnected and accessible networks aligns with a GPS study of Boston bikeshare users (Ethier et al., 2024).

Equitable Access to Bikeshare Services

While bikeshare systems aim to provide broad public access to cycling, empirical research reveals sociodemographic disparities in their usage patterns. Studies have found that bikeshare system members tend to be younger and more affluent than the general population (Fishman et al., 2015b; Shaheen et al., 2013). Gender disparities are also evident, with males typically dominating ridership numbers (Böcker et al., 2020; Nikitas, 2019). Furthermore, individuals aged 18-34 are 3.3 times more likely to be members than other age groups (Fishman et al., 2015b). This demographic pattern is particularly pronounced among highly educated populations in North America, where education levels show a strong positive association with cycling adoption (Vandenbulcke et al., 2011). Within this young adult cohort, two distinct subgroups emerge: students and early-career professionals. Students are often economically constrained and lack access to private vehicles, thus they utilize bikeshare as an affordable mobility solution (Vandenbulcke et al., 2011). Young professionals are likely choice-riders using bikeshare for multimodal commuting or recreational trips. Despite serving these varied needs within the same age bracket, the overall user base remains skewed.

Although initiatives focused on equitable access can shift these trends–evidenced by higher trip rates among lower-income users when stations were locally available in London (Ogilvie & Goodman, 2012) and e-bike systems in Beijing attracting less affluent and educated young males by overcoming distance and terrain barriers (Campbell et al., 2016)–significant challenges remain. These examples highlight the latent demand in underserved areas (DeMaio, 2009); however, the consistent demographic skew requires deeper examination of the specific challenges hindering equitable access to bikeshare services.

Particularly in the U.S., lower-income individuals and people of color (POC) are frequently less likely to have convenient access to bikeshare stations and are also less likely to use the service when physically available (Dill et al., 2022). While many systems now incorporate equity considerations into station siting (McNeil et al., 2017), research suggests that physical access alone is insufficient to overcome disparities in use, pointing to a complex web of barriers (Kodransky and Lewenstein, 2014, Stewart et al., 2013).

Cost emerges as a primary barrier for lower-income populations. High membership fees and concerns about liability for bikes disproportionately deter usage among lower-income respondents compared to higher-income groups (McNeil et al., 2017). Even where reduced-price memberships exist, lack of awareness is prevalent; only 31% of respondents in one study knew details about discounted options and even fewer knew how to use bikeshare (McNeil et al., 2017). Another practical concern that bikeshare could address is not owning or having barriers to purchasing bike related equipment (McNeil et al., 2017).

Beyond practical barriers that bikeshare programs might address, perceptions of safety and prevailing attitudes towards cycling significantly influence adoption. Concerns about liability for rented bikes, for example, were strongly expressed by lower-income populations surveyed

(McNeil et al., 2017). Physical safety is another factor; while the presence of bike lanes appears to motivate interest among higher-income POC, while lower-income POC express significant concerns about harassment or becoming a victim of crime while riding (Dill et al., 2022; McNeil et al., 2017). Furthermore, cultural attitudes present obstacles. In another survey many interviewees alluded to how biking in the U.S. is a predominantly wealthy, male, Caucasian driven activity" (Setterfield, 2016), which can implicitly exclude potential users.

Even when stations are placed in disadvantaged neighborhoods, usage patterns differ. Research from Chicago's Divvy system found that stations in these areas generated roughly two-thirds of average trips compared to other stations, had significantly lower proportions of annual members, and that ridership was strongly linked to local employment rates (Qian & Jaller, 2020). Interestingly, however, annual members from these communities tended to take longer trips, potentially indicating a greater reliance on the system for essential travel like work commutes once initial barriers to membership are overcome (Qian & Jaller, 2020). Furthermore, the maximum trip time taken by users in this group are very close to 30 minutes, the maximum amount of trip time Divvy offers members for free, suggesting that these populations try to make the most of their subscription benefit without incurring additional costs (Qian & Jaller, 2020). This suggests a need for potentially extended free ride time limits for members in these areas. While systems increasingly consider equity in siting, fees, and marketing (McNeil et al., 2017), achieving truly equitable bikeshare requires addressing a multifaceted group of financial, infrastructural, safety, awareness, knowledge, and cultural barriers.

Bikeshare Station Placement Methods

Optimal selection of bikeshare station locations to maximize ridership, ensure accessibility, and promote equity has evolved into a process that integrates geographic information systems (GIS), demand modeling, and demographic considerations. Modern approaches employ GIS-based multicriteria decision analysis to evaluate potential sites based on key factors such as population density, employment centers, transit accessibility, and cycling infrastructure quality (Fazio et al., 2020; García-Palomares et al., 2012). Additionally, demand coverage models leverage regression and discrete choice frameworks to quantify how different variables–such as land-use mix, employment density, and bike lane availability–influence ridership potential (Mix et al., 2022; Fighih-Imani & Eluru, 2016). Furthermore, demand coverage models utilize existing data from current cyclist trips and short car trips to identify potential cyclists, and bicycle crash data to identify the safety of potential stations (Larsen, 2013).

Another technique used in station siting is location-allocation optimization, which seeks to balance spatial equity with operational efficiency. Studies such as Banerjee et al. (2020) and Conrow et al. (2018) demonstrate how these models distribute stations to cover underserved areas while still prioritizing high-demand zones. Identification of suitable locations used a GIS approach and variables such as demand, attractiveness, and proximity to existing bikeshare stations. Other studies utilize GIS-based optimization factoring in population density, employment, education hubs, transit access, and recreational destinations (Wuerzer et al., 2012). Similarly, other studies have used these variables to develop scoring models, emphasizing placement in areas with strong mixed-use activity, safe cycling infrastructure, and proximity to transit (García-Palomares et al., 2012), directly translating desired characteristics into site suitability scores for comparison.

Despite these methodological advances, persistent equity gaps remain in bikeshare systems. Research shows that even when capital costs are covered, revenue-driven placement strategies tend to neglect disadvantaged neighborhoods (Qian & Jaller, 2020). To address this, recent frameworks incorporate buffer analysis to assess demographic coverage, ensuring stations are accessible to low-income and minority populations (Qian & Jaller, 2021). Other studies combine demand-driven metrics with equity-weighted adjustments; for instance, Hasan (2016) proposed redistributing Chicago's Divvy bikeshare stations to improve accessibility for marginalized communities.

Beyond identifying high-potential zones, practical placement algorithms utilize station spacing constraints to validate findings and ensure adequate network density without over-concentration. To promote accessibility, research recommends bike-sharing stations be placed within a 5-minute walk (250-300 meters) of each other; instead of increasing station spacing, cities should adjust station size (number of docks) to suit varying neighborhood demands (NACTO, 2015). For instance, Paris's Velib' system and Montreal's BIXI program space stations every 4 blocks (300 meters), allowing users to easily locate and return bikes. As shown previously land-use attractors also drive station placement (Shu et al., 2013). Studies emphasize location stations within 400 meters of transit stops and bike lanes (Fazio et al., 2020) and 200-300 meters of key destinations to maximize usage (Banerjee et al., 2020; García-Palomares et al., 2012).

GIS-based modeling and optimization allow for efficient bikeshare station placement; however, addressing persistent equity gaps necessitates the integration of demographic data and equity-weighted adjustments alongside demand-drive metrics. Optimal station siting requires an approach that combines operational efficiency, station-proximity validation, and equitable service provision.

METHODOLOGY

Data Sources

CapMetro Bikeshare's baseline network comprises 73 active stations in Austin, Texas (as of April 2025). Current station data location and dock configuration data was obtained directly from CapMetro staff and historical Metrobike station data from Austin's open data portal (data.austintexas.gov). Due to the recency of CapMetro Bikeshare's rebranding, historical Metrobike trip data (sourced from data.austintexas.gov) was used for analyzing past usage patterns. The full dataset contains over 2 million bikeshare trip end records along with the membership type of the rider, checkout and return stations, and trip duration and date. The majority of analysis utilizes data from January 2022 to July 2024 to capture trends without influence of outlying occurrences such as promotions or COVID-19 pandemic disruptions.

Potential future bikeshare demand was estimated using projected trip outputs from the POLARIS (Planning and Operations Language for Agent-based Regional integrated Simulation) Transportation System Simulation Tool (Auld et al., 2016). The base POLARIS code was developed by researchers at Argonne National Lab (Auld et al., 2016) and improved on by Kockelman and her students at UT Austin (for use with shared autonomous vehicle systems) (Fakhrmoosavi et al., 2024; Huang et al., 2021; Dean et al., 2022a; Dean et al., 2022b). Agent-based models like POLARIS simulate the complete daily activity and travel decision-making process of individual synthetic travelers, offering advantages over four-step models for capturing complex behavior. For this analysis, POLARIS simulations utilized demographic inputs (Census and American Community Survey), employment data, and network characteristics provided by the Capital Area Metropolitan Planning Organization (CAMPO) for the Austin region. The simulation was executed by Kentaro Mori, a doctoral researcher in the Department of Civil, Architectural and Environmental Engineering at the University of Texas at Austin. This study utilized the resulting 2035 average weekday travel patterns for a 25% population sample. To focus on trips most relevant to bikeshare potential three short-distance transportation modes were selected: single-occupancy automobile trips under 3 miles, bicycle trips, and pedestrian trips (Shaheen et al., 2010). The datasets featured 136,331 walk trips, 59,397 bike trips, and 780,479 short distance auto trips.

Traffic Analysis Zones (TAZs) served as the primary spatial unit for aggregating simulated demand trip ends with geographic attributes within Austin's city limits (N=1,009 relevant zones). Each zone features attributes such as population and employment counts, land-use characteristics, and demographic information. Additionally, this study incorporates CAMPO transit stops location data and roadway networks. Traffic analysis zones provide a standardized framework for analysis of POLARIS simulation data, Metrobike trips, and CapMetro Bikeshare stations.

Data Analysis

The current station distribution shown in Figure 1 follows conventional urban bikeshare deployment patterns (Bateman et al., 2021), concentrating in Austin's Downtown central business district and University of Texas (UT) campus areas where high population density and strong public transit connectivity generate consistent demand. However, these two core areas remain separated by a 1-mile gap without stations. Stations in the downtown and UT neighborhoods serve commuting needs for students and employees and retail uses for residents and visitors. The service network extends along retail corridors and recreational areas to the east, south, and west.

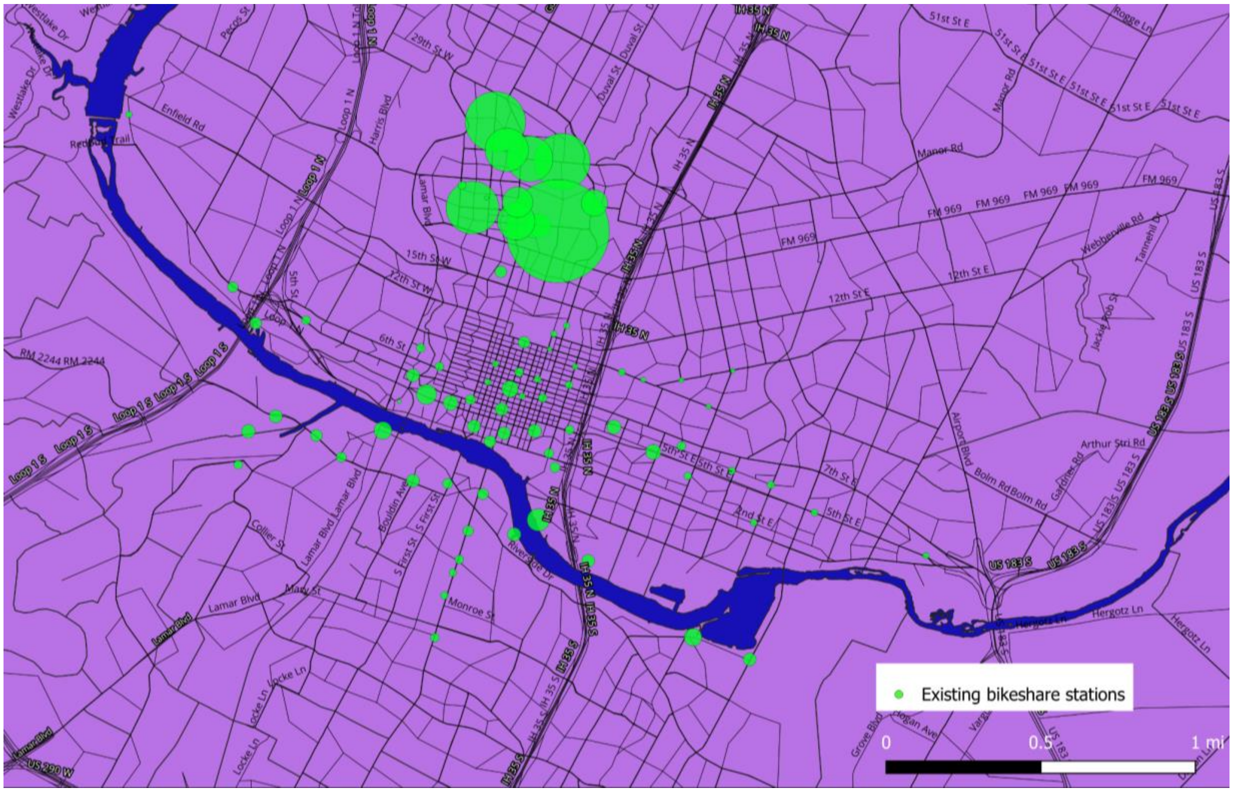

Figure 1: April 2025 CapMetro Bikeshare stations sized by 2022-2024 Metrobike trip end counts

The most popular Metrobike stations from January 2022 to July 2024 were concentrated in the UT Neighborhood. Analysis of origin-destination station pairs by trip counts supports these findings. In the 50 most popular station pairs in the 2022-2024 period, only 3 pairs did not begin and end outside of the UT Neighborhood. All three pairs exhibited round-trip patterns, likely representing recreational usage, given their proximity to Colorado River activities–a finding consistent with Kim et al.'s (2025) analysis of leisure-oriented bikeshare trips. In contrast, the UT neighborhood's most frequent station pairs typically feature different origin and destination stations, indicating the likelihood of these stations being used for commuting between residential and campus locations.

Table 1: 2022-2024 Metrobike Trips Descriptive Statistics

Description		**Statistic**
Trips	Number of trips	730,869
Membership or pass type	Student Membership	50.18%
	Local31	14.35%

	Local365	11.25%
	Explorer	10.07%
	Pay-as-you-ride	7.85%
	3-Day Weekender	4.02%
	24 Hour Walk Up Pass	1.05%
Bike type by recorded trips	Classic	10.40%
	Electric	89.60%
Duration (minutes)	0-5	23.22%
	5-10	32.06%
	10-15	11.51%
	15-30	15.80%
	>30	17.41%

The trip data from January 2022 to July 2024 shown in Table 1 reveals a dominance of Student Membership ridership in historic Metrobike usage, reinforcing the spatial analysis of popular station pairs. Local non-student passes make up the second largest segment, suggesting commuters outside of UT consistently use Austin's bikeshare service. Short-term passes contributed 23% of trips, indicating modest tourist or casual use.

Short trips (0-10 minutes) make up over half of all rides which is consistent with commuting behavior. These quick trips predominantly serve utilitarian purposes such as on-campus off-campus movement for students or last-mile connections for downtown workers. Longer trips (>15 minutes, 33.2%) may include leisure or multimodal connections. The smaller share indicates that bikeshare in Austin has untapped potential in tourist and retail-oriented rider segments that could be cultivated through targeted station placement near attractions and shopping districts.

Since historical Metrobike trip data lacks recorded distances, this analysis imputed distance based on trip duration using an estimated average e-bike speed. A standardized speed of 7 mph was selected for these calculations, informed by reported average speeds for e-bikeshare systems in other cities such as 6.5 mph observed in Richmond, Virginia (Yang et al., 2024), 7.4 mph in Helsinki, Finland (Willberg et al., 2021), and an average 7.9 mph across the U.S. (NACTO, 2020).

Analysis of POLARIS simulated short-distance trip data revealed that it has strong potential for modeling bike trips in an expanded network. After cleaning, short auto trips (< 3 miles) averaged 1.61 miles in distance, closely matching Metrobike's imputed average trip length of 1.89 miles. This alignment suggests that bikeshare already effectively serves trips of similar length to those currently made by private vehicles. Simulated walking trips show a mean distance of 2.25 miles with a peak frequency in the 1-2 mile range, likely reflecting recreational trail use and first/last mile connections to transit. Walks exceeding two miles suggest potential first/last mile gaps that strategic bikeshare placement could address (Bourne et al., 2020). Simulated bicycle trips (mean distance of 4.18 miles), concentrated in the 2-4 mile range, align well with e-bike capabilities, suggesting an opportunity to capture cyclists making medium-length trips. Trips beyond 5 miles remain challenging without expanded protected bike infrastructure.

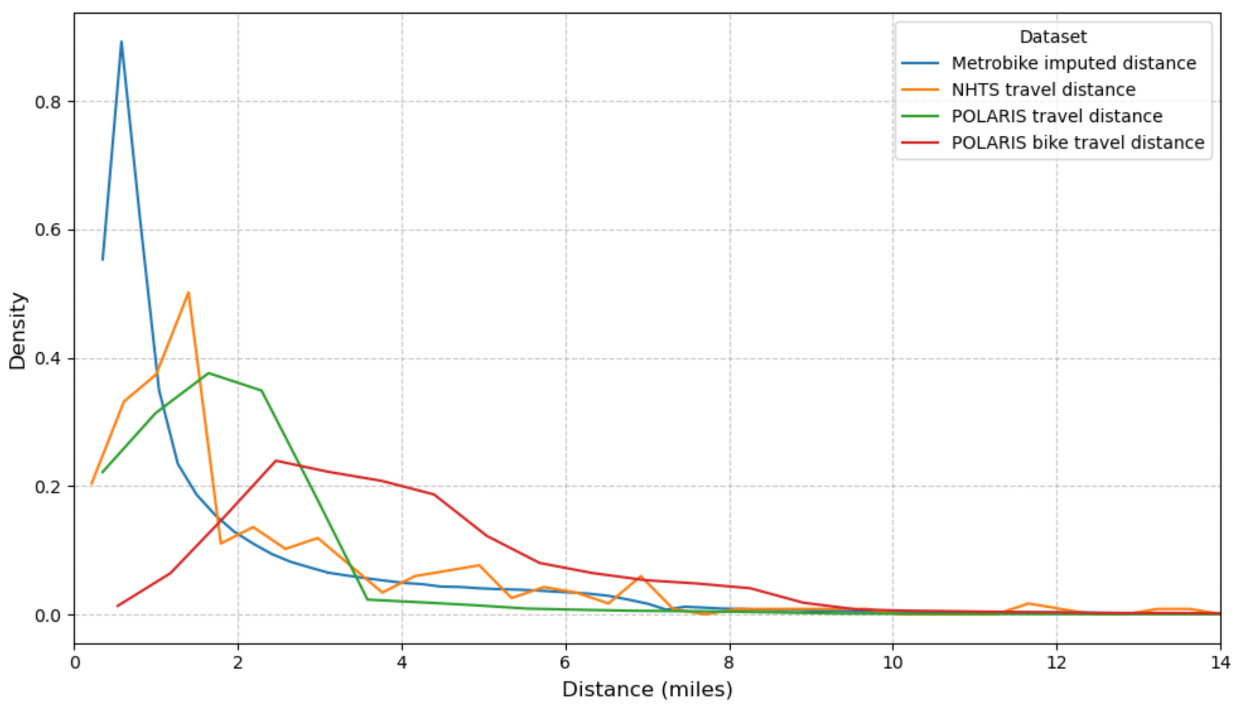

Figure 2: Metrobike 2022-2024 Trips Imputed Distance vs. NHTS Bike vs. POLARIS (All Modes) vs. POLARIS (Bike) by Trip Distance Density

The distance comparison in Figure 2 reveals differences in trip patterns between Metrobike and broader cycling activity. Metrobike trips show a concentration at very short distances (peak density at 0.45-0.55 miles), with a sharp drop-off beyond 3 miles–a pattern observed in urban bikeshare systems and heavily influenced by the UT campus' dominance in the network. National Household Travel Survey (NHTS) 2022 data, which consists of personal bike, e-bike, and bikeshare data, displays a broader distribution with a peak at ~1.5 miles. NHTS bike trip density extends to the 14 mile-mark, validating the general cycling behavior captured in both the POLARIS and Metrobike datasets. POLARIS bike trips represent more recreational cycling compared to Metrobike's utilitarian short-hop pattern. POLARIS walk, bike, and short auto trips display a smoother distance decay when compared to Metrobike, indicating how system expansion to key POLARIS trip end locations could result in longer average e-bike trips.

Station Score Index

The demand estimation used in this study utilizes POLARIS trip ends per acre as the primary metric to identify zones with high latent bikeshare potential. This approach is justified by three key factors: First, as an agent-based travel demand model, POLARIS simulates individual trip-making behavior based on empirically validated determinants of bikeshare usage, including land-use mix, employment density, transit accessibility, and socioeconomic factors–all variables strongly associated with bikeshare station siting in the literature review. Second, the transition to a fully electric fleet necessitates a forward-looking demand estimation rather than relying on historical Metrobike data, which reflects a geographically constrained system that does not utilize only e-bikes. Third, by utilizing trips per acre, the analysis avoids artificially prioritizing larger zones while capturing demand density.

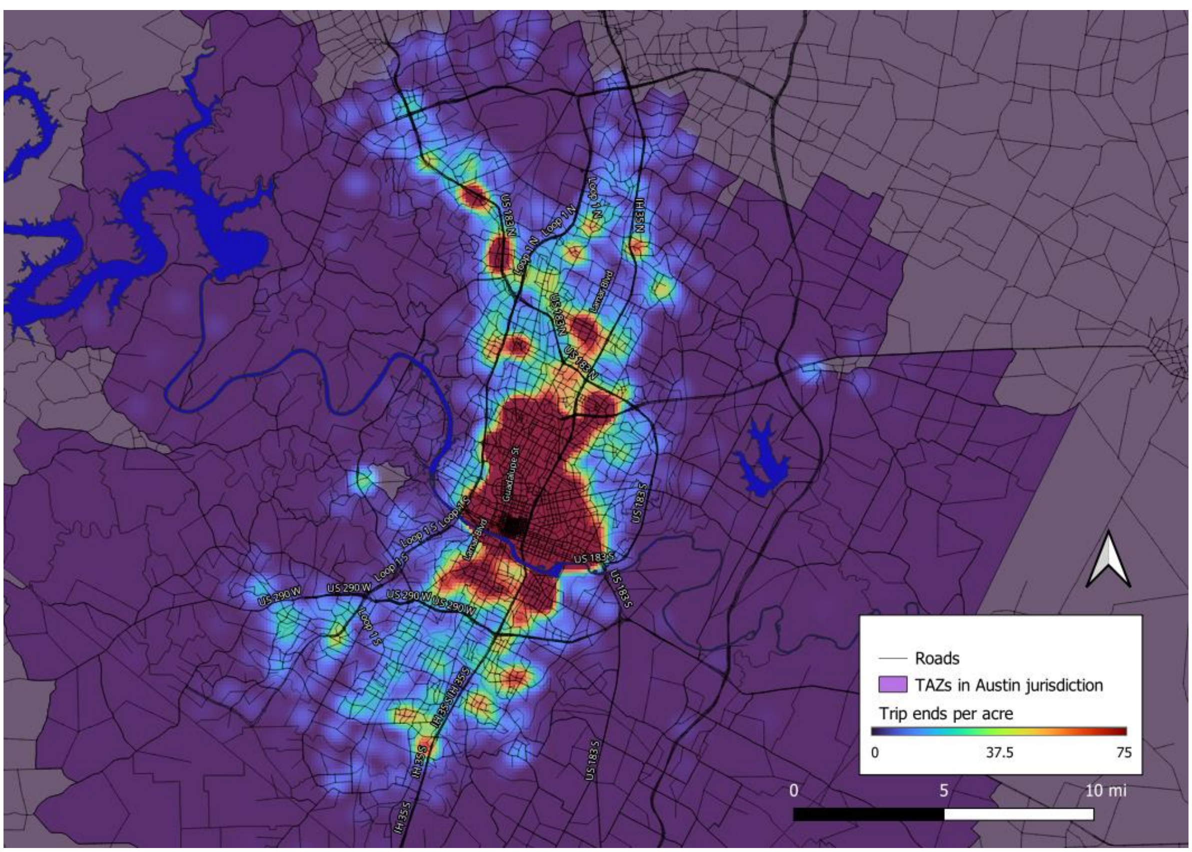

Figure 3: POLARIS Trip Ends per Average Weekday per TAZ Acre in Austin's City Jurisdiction

The study is limited to zones within Austin's city limits–the area available for CapMetro Bikeshare expansion. Figure 3 shows demand density primarily clustered in the Downtown and UT neighborhoods, which have existing high-performing stations, Hyde Park and Central Austin, and Central East Austin. Notably, only 14 of the top 58 (5%) high-demand zones (> 75 trip ends per acre) currently have bikeshare stations. Development within this area can connect residential trip-generating zones to high-demand destinations like employment and retail centers, improve access to transit, and serve neighborhoods with strong latent demand but limited current mobility options.

The demand metric was used to anchor a weighted score index, similar to Arellana et al. (2020). Supplementary GIS variables were selected based on empirical findings from the literature review and CapMetro's strategic goals of equity, connectivity, and ridership growth. These include population data (e.g., residential, employment, retail employment), land-use characteristics (e.g., mixed-use percentage, park area), transit connectivity (zone transit stop counts), and equity considerations (minority population share, low-income flags based on CapMetro definitions). All features were z-score normalized before weighting to enable comparison and address skewness.

The station score for each zone (i) is calculated as:

$$StationScore_i = \sum_{j=1}^{9} w_j \cdot Z(x_{ij})$$

Where:

- w_j represents weights assigned to each feature (summing to 100%)
- $Z(x_{ij})$ is the z-score normalized value of feature j in zone i

This approach balances potential demand with practical implementation needs, providing a transparent, data-driven foundation for expansion decisions while accommodating policy judgements through adjustable weights.

Zone Selection Algorithm

The station placement algorithm follows an iterative, score-driven process to expand the existing bikeshare network while maintaining operational efficiency. The initialization phase restricts candidate zones to those within a 1-mile Euclidean distance of existing stations (measured from zone centroids), maintaining network connectivity. Zones within ¼ mile of current stations receive a 50% score penalty to prevent over-concentration. The penalty is based on CapMetro bikeshare's average station size of 11 docks and scale with the number of docks within a zone. Prior to penalty application, all z-score normalized features are shifted to a minimum of 0, ensuring accurate penalty effects across all variables.

The algorithm iteratively places docks in zones until reaching the target capacity of 3,000 docks (approximately 265 stations using a 11.3 dock average). In each iteration the highest-scoring eligible zone is selected for expansion. If the zone does not have existing stations (< 7 docks), it will receive a new small station (7 docks). If the zone has an existing bikeshare station (with at least 7 docks) it will gain 4 additional docks (matching CapMetro's standard expansion increment). The 1-mile expansion radius is recalculated around if a new zone is added, dynamically updating the candidate zone pool.

RESULTS

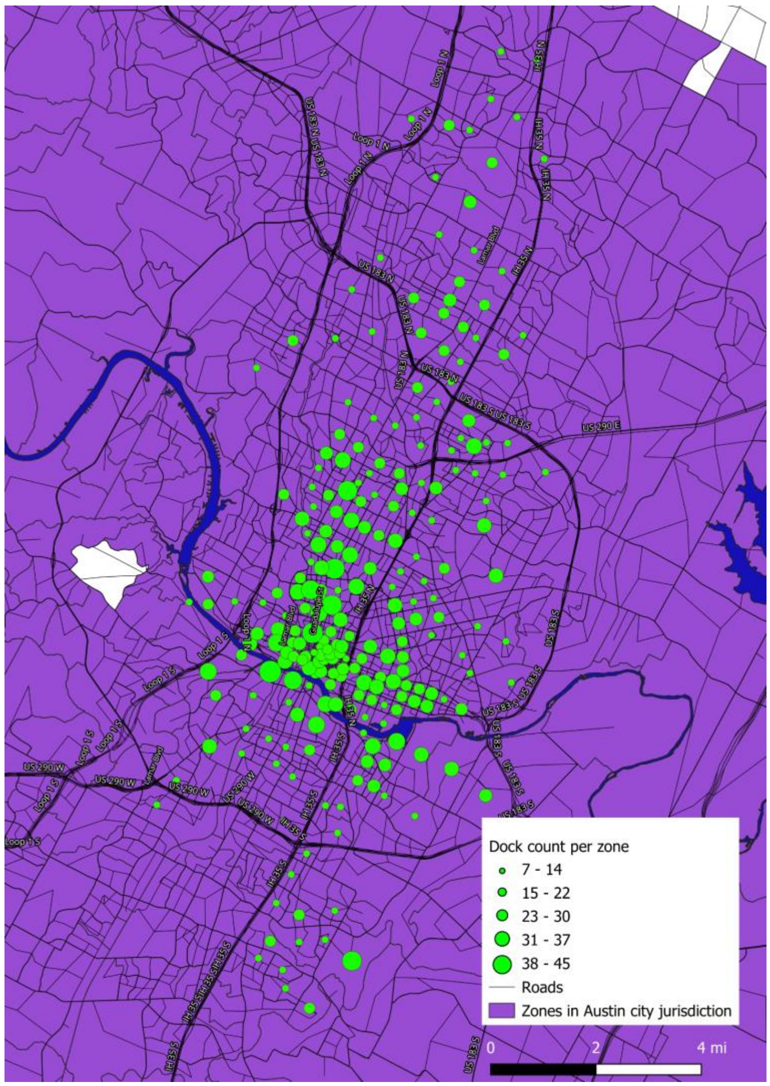

Figure 4: Dock Counts per Zone for Austin's Proposed Expansion Service Area

The proposed bikeshare network expansion offers significant potential to enhance micromobility access across Austin. By increasing the station density (adding 174 new zones and 1,902 docks)) while also expanding the zonal service area almost tenfold(3,330 to 31,305 acres^2), the plan aims to meet latent e-bike demand and serve a much larger and more diverse population of Austinites. The proposed zones cover an increased number of public transportation stops (from 152 to 1,039), providing opportunities for improved integration with public transportation. Figure 4 shows that dock counts per acre are still densest in the UT and Downtown neighborhoods; however, the coverage area now stretches from Wells Branch Parkway (north) to Bluff Springs (south), and from University Hills (east) to Westfield (west). The proposed area creates a contiguous network that prioritizes high-demand corridors while addressing historical gaps in underserved neighborhoods.

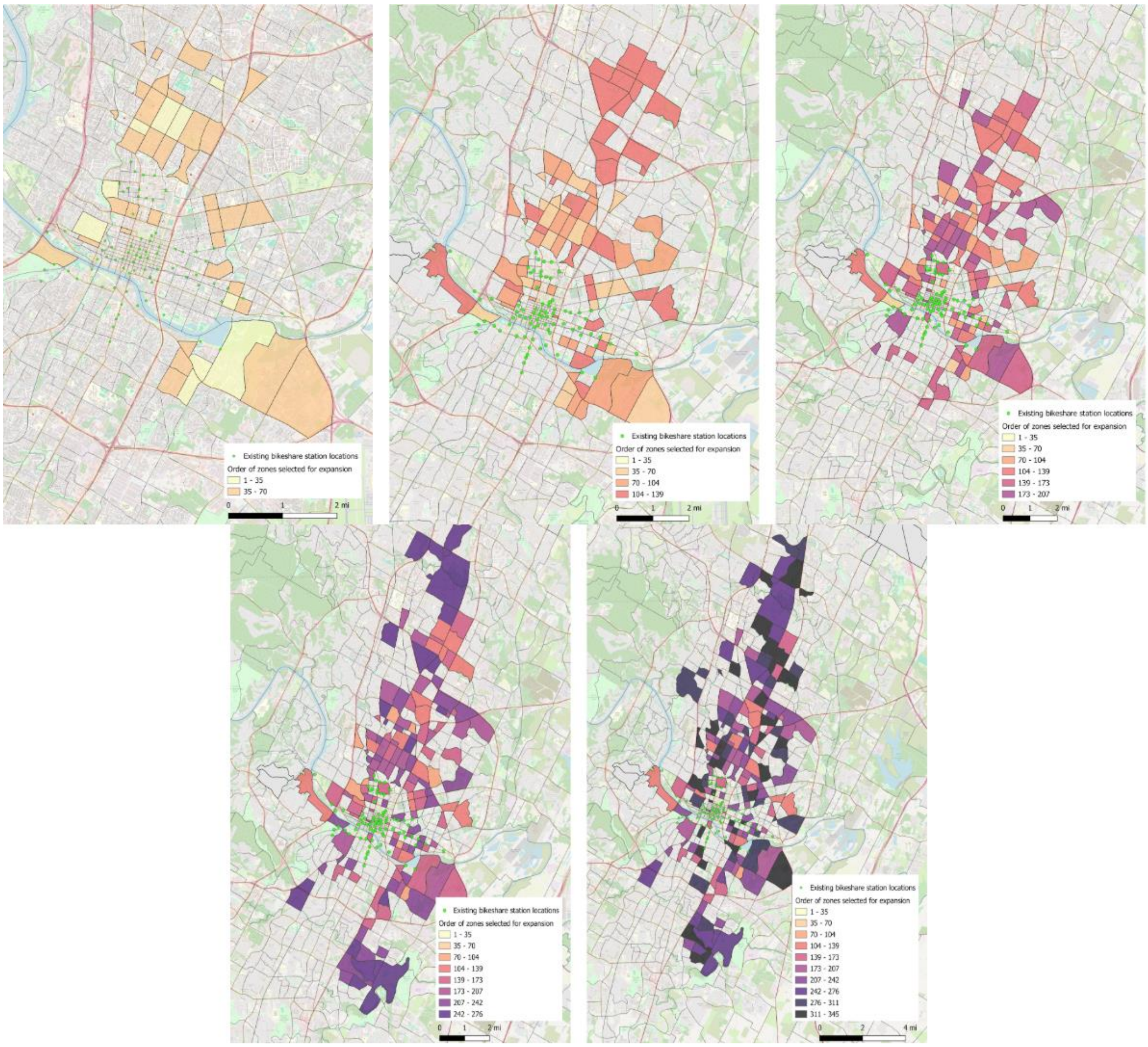

Figure 5: Order of zones selected for bikeshare dock expansion/addition (20, 40, 60, 80, and 100% of total expansion)

The algorithm executed 345 iterations, generating a phased expansion strategy (Figure 5) that balanced strengthening the existing networking, expanding geographically, and equity priorities. The initial phase focused on reinforcing and connecting the core service areas in the Central Business District and the University of Texas neighborhood, while also initiating infill and expansion into adjacent high-demand neighborhoods like Hyde Park, Clarksville, and parts of East Austin. Phases 2 and 3 prioritized geographic expansion, extending the network significantly northward (towards Mueller & North Central Austin) and southward (along South

Lamar corridors), reaching corridors with high transit densities. This growth also committed to infill to bridge expanded zones with the established service area. Phase 4 provided equity solutions, targeting specific underserved communities such as Dove Springs in Southeast Austin, alongside continued expansion to major employment centers (e.g., Tech Ridge) and recreational hubs (e.g., Walnut Creek).

The service area expanded northward to the North Campus and Hyde Park neighborhoods. This area includes some zones in Rosedale, a primarily residential neighborhood centered around the Ramsey Neighborhood Park. North Campus currently has access to nearby stations on Dean Keeton; however, the majority of North Campus is not currently served by CapMetro Bikeshare. Hyde Park and the bordering Triangle State neighborhood is a high-demand area that includes retail, residences, dining, and parks. Zones added in West Campus, Clarksville, and Downtown not only cover areas exhibiting high potential demand, but also join the Downtown service area to the UT neighborhood. Expansion into Rosewood and East Austin bridge gaps in historically underserved neighborhoods, linking residential areas to transit corridors along East Riverside Drive and Pleasant Valley Road. The final iteration provided infill solutions and added institutions like St. Edward's University, creating a relatively comprehensive coverage across Austin.

It is important to note that while the proposed solution selected various zones in North Austin, major activity centers like The Domain and Q2 Stadium were not prioritized for expansion. Although generally high-traffic areas, the underlying modeled demand potential was relatively low in these zones according to the scoring index. The omission of zones with high overall activity and vehicular traffic indicates that these features do not automatically equate to high bikeshare demand. This suggests that trip purpose, existing infrastructure connectivity, and mode choice in these areas may make them less suitable for bikeshare ridership according to the model used.

DISCUSSION

The proposed expansion offers significant potential to enhance micromobility access across Austin by increasing transit stops served in the network by nearly sevenfold. This provides opportunities for improved integration with public transportation, including potential rail line connections. While the zone selection algorithm emphasizes proximity to transit stops, it does not pinpoint exact station locations. Therefore, to ensure effective first and last mile solutions, it is recommended that bikeshare stations placed within these selected zones be sited specifically within 0.6 miles (approximately 1 km) of a transit stop (Basu & Ferreira, 2021). This strategy will significantly extend the service range of public transportation across a larger portion of Austin. The greater connectivity and resulting reduction in car-dependence also helps Austin meet its Strategic Mobility Plan goal of having less than 50% of commuters driving alone by 2039. The large scale of this proposed expansion aligns with research suggesting that larger, denser bikeshare station distribution results in higher utilization rates (NACTO, 2020).

Beyond enhancing transportation access, the proposed bikeshare expansion offers community benefits. The expanded zones include high-potential demand mixed-use districts (e.g., South Lamar, the Triangle, Mueller, Tech Ridge). Placement of stations in these zones near retail and dining services is likely to increase foot traffic and stimulate local economic activity. Similarly, expanding station access to cultural attractions and event venues has the potential to boost local tourism.

The proposed zone expansion provides new, convenient access to over 40 parks citywide, including trail hubs such as Pease Park, Edward Rendon Sr. Park, and Walnut Creek Metropolitan Park. Stations placed near parks and trail hubs are expected to be popular, supporting recreation and healthier lifestyles while offering users access to safer cycling environments away from traffic (Guo & He, 2020; Vandenbulcke et al., 2011). Moreover, the all-electric fleet enhances accessibility: e-bikes make cycling feasible for a wider range of fitness levels by providing moderate physical activity (Bourne et al., 2018) and simultaneously allow users to undertake longer trips than might be practical on conventional bikes.

The proposed expansion prioritizes equitable access to micromobility. The number of low-income flagged zones served by CapMetro Bikeshare's network will increase substantially, from 6 to 44, and the number of diverse demographic zones (>50% non-white population) served will rise from 14 to 99. Within these areas, the served population increased from 8,902 to 116,770 in low-income zones and from 15,018 to 235,197 in demographically diverse zones. By prioritizing East Austin and low-income areas like Dove Springs, the plan directly addresses historical inequities in transportation access and expands opportunities for underserved communities. Additionally, the plan enhances connectivity for multiple student populations by strengthening service around UT Austin and adding coverage near St. Edward's University and multiple Austin Community College campuses. The creation of a contiguous network bridges previous gaps like the one between Downtown and the UT neighborhood. An unbroken bikeshare network would enable more seamless travel across the city's core and connect residential areas in North, South, East, and West Austin to high-demand destinations and transit corridors.

FINANCIAL ANALYSIS

The proposed expansion leverages a $11.3 million federal grant covering capital costs for bikes (~$3,000 each, including backup battery) and stations (~$1,600 per dock, assuming 1.9 docks per bike based on CapMetro figures) over a 6-year rollout period, totaling an estimated $8.8M in capital expenditures. Operations and management (O&M) costs, estimated at $2,500 per bike per year and scaling with fleet size, are covered by user fares, advertising (typically 20-30% of O&M costs), and City funding via an Interlocal Agreement (Simpson, personal communication, 2024).

Table 2: Estimated CapMetro Expenses Over the 6-Year Expansion Period

Year	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2024-2029**
Proposed phase	Initial re-opening	1	2	3	4	5	All
# of docks added	953	419	384	368	381	350	2,855
# of new stations (11 docks/station)	87	38	35	33	35	32	260
# of new bikes	477	210	192	184	191	175	1,429
Total # of docks	953	1,372	1,756	2,124	2,505	2,855	2,855
Total # of bikes	477	687	879	1,063	1,254	1,429	1,429

Costs							
Docks added (Capital cost)	$1,504,737	$661,579	$606,316	$581,053	$601,579	$552,632	$4,507,895
Bikes added (Capital cost)	$1,431,000	$630,000	$576,000	$552,000	$573,000	$525,000	$4,293,000
Total capital cost	**$2,935,737**	**$1,291,579**	**$1,182,316**	**$1,133,053**	**$1,174,579**	**$1,077,632**	**$8,794,895**
O&M cost	**$1,192,500**	**$1,717,500**	**$2,197,500**	**$2,657,500**	**$3,135,000**	**$3,572,500**	**$14,472,500**
Revenue projections							
Fare revenue	$332,469	$665,760	$1,186,650	$1,435,050	$1,692,900	$1,929,150	$7,241,979
Farebox recovery rate	27.9%	38.8%	54.0%	54.0%	54.0%	54.0%	50.0%
Advertisement revenue	$298,125	$429,375	$549,375	$664,375	$783,750	$893,125	$3,618,125
Total revenue	**$630,594**	**$1,095,135**	**$1,736,025**	**$2,099,425**	**$2,476,650**	**$2,822,275**	**$10,860,104**
Funding sources							
TASA federal grant (Capital Funding)	$11,300,000	$0	$0	$0	$0	$0	$11,300,000
Cumulative TASA federal grant balance remaining	$8,364,263	$7,072,684	$5,890,368	$4,757,316	$3,582,737	$2,505,105	$2,505,105
Financial gap							
Operational gap	-$561,906	-$622,365	-$461,475	-$558,075	-$658,350	-$750,225	-$3,612,396
Operational deficit rate	47.1%	36.2%	21.0%	21.0%	21.0%	21.0%	25.0%

Analysis of Table 2 indicates the expansion, while increasing ridership potential, does not guarantee operational profitability. CapMetro's planned fare increase (effective August 1, 2025) is crucial; it is projected to boost the farebox recovery rate from ~28% initially to ~54%--exceeding typical transit recovery rates but still leaving an operational deficit. Over the 6-year period, the operational gap is estimated at $3.6M (Table 2), highlighting the system's reliance on external subsidies (common for public bikeshare systems in the U.S.) typically provided by the City and potential partnerships (Buehler, in press, 2021; CapMetro, 2021). While overall cash flow appears positive (~$2.5M surplus assuming City contribution), this figure relies heavily on the federal grant–which is restricted to capital expenditures and may also be needed for future asset replacements not quantified here due to vendor uncertainty–and masks the underlying operational operational loss, as revenue covers only 75% of O&M costs over the period.

Despite not being financially profitable for CapMetro, the expansion is strategically advantageous, aligning with its public service mission benefitting Austin's residents, commuters, and visitors by leveraging the City of Austin's bike lane expansion and has the potential to increase overall transit ridership.

Private and public holistic costs vs. benefits

Beyond CapMetro's finances, the expansion is projected to generate substantial public and private economic benefits. These were estimated using established methodologies, drawing on mode shift data, health impact assessments, and user savings surveys from similar programs and applied to Austin's projected ridership over the expanded bikeshare system. Future ridership was estimated by extrapolating the number of trips per docked e-bike per day (2.37–closely aligning with the national average of 2.2 trips per e-bike per day) from 2022-2024 Metrobike data (NACTO, 2022).

Table 3: Estimated Economic Impacts of Proposed CapMetro Bikeshare System Over the 6-Year Expansion Period

Year	2024	2025	2026	2027	2028	2029	2024-2029
Proposed phase	Initial re-opening	1	2	3	4	5	All
Total # of bikes	477	687	879	1,063	1,254	1,429	1,429
# of projected users	13,833	19,923	25,491	30,827	36,366	41,441	167,881
# of projected trips	413,759	594,289	760,379	919,548	1,087,745	1,236,156	5,011,877
Public economic impact							
Economic activity generated	$1,309,155	$1,885,513	$2,412,468	$2,917,467	$3,441,678	$3,921,976	$15,888,258
Health economic savings	$375,407	$539,204	$689,898	$834,314	$986,920	$1,121,575	$4,547,317
Total Public Economic Benefit	**$1,684,562**	**$2,424,716**	**$3,102,366**	**$3,751,781**	**$4,428,598**	**$5,043,551**	**$20,435,575**
Private economic impact							
Total transportation savings	$3,486,306	$5,007,438	$6,406,897	$7,748,045	$9,165,256	$10,415,763	$42,229,704
Transportation savings per user (~86 trips/year)	$1,017.64	$1,017.64	$1,017.64	$1,017.64	$1,017.64	$1,017.64	$6,105.84
Net Transportation Savings (per Annual Member)	$931.64	$904.97	$867.64	$867.64	$867.64	$867.64	$5,307.17
Net Transportation Savings (per Monthly Member)	$885.64	$815.64	$717.64	$717.64	$717.64	$717.64	$4,571.84

Table 3 shows that over the 6-year expansion, public economic benefits are estimated at $20.4M, primarily from increased local economic activity (~$15.9M, derived from bikeshared induced user spending trip estimates based on Ricci, 2015) and healthcare savings (~$4.5M, derived from valuing averted mortality rates resulting from mode switching to bikeshare based on Clockston & Rojas-Rueda, 2021). This yields a strong public cost-benefit ratio of approximately 5.66 in public benefit for every dollar of the estimated $3.6M City operational contribution.

Private benefits to users are even larger, estimated at $42.2M in avoided transportation costs (fuel, parking, maintenance, rideshare fees) over 6 years. After accounting for membership fees annual and monthly members still experience significant annual savings (Capital Bikeshare, 2011 survey data, adjusted for inflation).

Analyzing per-trip impacts provide a holistic view of the proposed solution's value:

Table 4: Estimated Economic Impacts per Trip (assuming 2.37 trips per day per bike)

	Costs			Benefits						
Source	O&M	Bike CapEx	Dock CapEx	Economic activity	Health savings	Deaths avoided	Deaths caused	Rideshare savings	Car savings	**Net benefit**
Bikeshare value/trip	-$2.89	-$0.86	-$0.90	$3.17	$0.91	1.00E-06	5.19E-08	$4.00	$3.43	**$6.86**

Table 4 shows that each trip incurs amortized operational and capital costs totaling approximately $4.65; however, it generates estimated benefits of around $11.51 through local economic activity, public health savings, and direct user automobile/rideshare transportation costs avoided. This results in a substantial estimated net benefit of $6.86 per trip. Health savings suggest that a shift towards cycling avoids approximately 5 premature deaths (through reduced air pollution exposure and increased exercise) and over 200 disability-adjusted life years over the span of the expansion. These benefits vastly outweigh the minor increase in collision risks (estimated at ~0.26 deaths and ~2.7 DALYs caused).

LIMITATIONS

Methodological limitations include zone-level station placement, which requires street-level refinement considering local street and infrastructure geometry. The centroid-based approach necessitates manual adjustments for dock distribution in high-capacity or large zones. Furthermore, input data limitations such as using weekday-only POLARIS simulations and failure to include transit ridership data into mode switching hinders the predictive power of the model. The study's use of zonal trip ends results in generalized unidirectional demand and thus requires greater nuance to inform rebalancing strategies.

The financial and economic impact analysis also faces limitations. Cost estimations exclude long-term asset replacement costs and fail to consider the monetary implications of the new operations base. The cost model further assumes a linear relationship between the number of bikes in the system and the O&M costs, failing to reflect scaling complexities and costs associated with rebalancing in a large, geographically diverse network, particularly given potentially asymmetric trip patterns often observed in low-income or outlying zones (Qian & Jaller, 2021). Revenue projections omit variable income sources (like diverse membership options and overage fees) and the financial impact of recommended equity fares. Achieving the plan's equity goals likely necessitates reliance on subsidies or partnerships beyond user revenue, given the known cost barriers facing underserved populations (McNeil et al., 2017). Furthermore, the lack of a specific discount rate prevented a Net Present Value calculation, and the economic assessment omitted several public externalities such as noise reduction, congestion or infrastructure savings, and public space costs

CONCLUSION

This study proposes an expansion plan for Austin's CapMetro Bikeshare system to improve mobility and address the city's long-term growth goals. A multi-criteria approach that combined potential bikeshare demand with GIS data was used to design a bikeshare network balancing operational efficiency with equitable access for underserved populations.

Traffic analysis zones within Austin's city limits were ranked on bikeshare station fitness using a weighted scoring index developed from variables identified in literature to be associated with bikeshare ridership. Potential bikeshare demand, modeled using the POLARIS Transportation System Simulation Tool (an agent-based travel modeling platform), formed the primary component of the scoring index. Supporting factors–such as land-use characteristics, transit connections, and demographic variables aligned with CapMetro's equity objectives–were also integrated to create a more comprehensive and customizable assessment of station fitness.

The proposed expansion significantly increases the network size from 73 stations to ~265 stations across 174 new zones. The network extends CapMetro Bikeshare's geographic reach to Wells Branch Parkway, Bluff Springs, University Hills, and Westfield in the north, south, east, and west directions, respectively. The proposed station placements bridge existing gaps in the network while creating a larger, contiguous service area. The expansion integrates service with up to 1,039 transit stops, creating more opportunities for multi-modal travel and first and last mile connections across the city. The larger service area encompasses historically underserved populations, including Dove Springs and parts of East Austin, contributing to CapMetro's equity goals. Access to recreation is also greatly enhanced, with the network now reaching over 40 parks and major trail hubs.

The proposed zonal expansion provides a data-driven roadmap directly informing CapMetro's $11.2M expansion. The expansion plan supports the Austin Strategic Mobility Plan's goal of achieving a 50/50 mode split away from single-occupancy vehicles. By significantly enhancing multi-modal connectivity the expanded network makes the alternatives to driving alone more viable, thus reducing car dependency for certain trips (Fishman et al., 2013).

Beyond the spatial and network impacts quantified by the GIS-based methodology, the study conducted a financial and economic analysis of the proposed expansion. This analysis indicates that while the bikeshare operation is projected to face an operations deficit (~$3.6M over the 6-year period), the capital costs are likely feasible within the available grant funding. Despite the operational deficit, the expansion is argued to be strategically advantageous for CapMetro, aligning with its mission and broader network integration goals. Furthermore, the analysis estimated significant economic impacts for the public and individual users. The total public economic benefit (totaling ~$20.4M, comprising estimated economic activity and health economic savings) is projected to considerably outweigh the City of Austin's required financial contribution, yielding a strong undiscounted cost-benefit ratio. Individual users are also estimated to benefit substantially from private transportation savings, which are projected to significantly exceed membership costs.

Despite the potential benefits of the proposed strategy, its primary limitation is that station placements are identified at the zone level. Applicable station placement requires further analysis of prioritized zones using street network data to determine optimal street-level siting. The demand modeling relied on weekday, zone-aggregated POLARIS simulation data lacking public transportation data, suggesting future modeling could incorporate these elements alongside weekday and event data for a more comprehensive demand model and better informed rebalancing strategies. Finally, as station access alone does not guarantee equitable use (Dill et al., 2022), future research should evaluate the effectiveness of complementary policies in Austin, such as proposed equity fares and targeted outreach, to promote ridership among historically underserved communities.

ACKNOWLEDGEMENTS

The author appreciates Dr. Kara M. Kockelman and Dr. Emre Yucel for all their suggestions, guidance, and helpful comments. Additionally, this study would not be possible without Kentaro Mori's assistance in providing data and running the POLARIS simulation.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Danny Xie, Dr. Kara Kockelman, Dr. Emre Yucel; data collection: Danny Xie, Dr. Kara Kockelman; analysis and interpretation of results: Danny Xie, Dr. Kara Kockelman, Dr. Emre Yucel; draft manuscript preparation: Danny Xie, Dr. Kara Kockelman, Dr. Emre Yucel.

All authors reviewed the results and approved the final version of the manuscript.

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING

The authors disclosed no financial support for the research, authorship, and/or publication of this article.

REFERENCES

1. Fishman, E., & Allan, V. (2019). Bike share. In Advances in Transport Policy and Planning (Vol. 4, pp. 121–152). Elsevier. https://doi.org/10.1016/bs.atpp.2019.05.003
2. Shaheen, S. A., Zhang, H., Martin, E., & Guzman, S. (2011). China's Hangzhou Public Bicycle: Understanding Early Adoption and Behavioral Response to Bikesharing. *Transportation Research Record, 2247*(1), 33-41. https://doi.org/10.3141/2247-05
3. Campbell, B. (2024). *Bicycle sharing system*. EBSCO Research Starters.
4. Li, Q., Luca, D., Fuerst, F., & Wei, Z. (2024). Success in tandem? The impact of the introduction of e-bike sharing on bike sharing usage. *Research in Transportation Economics*,[1] *107*, 101476. https://doi.org/10.1016/j.retrec.2024.101476
5. Lu, Y., Prato, C. G., & Corcoran, J. (2021). Disentangling the behavioural side of the first and last mile problem: The role of modality style and the built environment. Journal of Transport Geography, 91, 102936. https://doi.org/10.1016/j.jtrangeo.2020.102936.
6. Fishman, E., Washington, S., & Haworth, N. (2013). Bike share: A synthesis of the literature. *Transport Reviews*, *33*(2), 148-165. https://doi.org/10.1080/01441647.2013.775612

7. Parkes, S. D., Marsden, G., Shaheen, S. A., & Cohen, A. P. (2013). Understanding the diffusion of public bikesharing systems: Evidence from Europe and North America. *Journal of Transport Geography*, *31*, 94-103. https://doi.org/10.1016/j.jtrangeo.2013.06.003
8. Kåresdotter, E., Page, J., Mörtberg, U., Näsström, H., & Kalantari, Z. (2022). First Mile/Last Mile Problems in Smart and Sustainable Cities: A Case Study in Stockholm County. *Journal of Urban Technology, 29(2),* 115–137. https://doi.org/10.1080/10630732.2022.2033949
9. Fishman, E., Washington, S., & Haworth, N. L. (2015a). Bikeshare's impact on active travel: Evidence from the United States, Great Britain, and Australia. *Journal of Transport & Health*, *2*(2), 135–142. https://doi.org/10.1016/j.jth.2015.03.004
10. Bourne, J. E., Cooper, A. R., Kelly, P., Kinnear, F. J., & Timperio, A. (2020). The impact of e-cycling on travel behaviour: A scoping review. *International Journal of Behavioral Nutrition and Physical Activity*, *15*, 114. https://doi.org/10.1016/j.jth.2020.100910
11. Ricci, M. (2015). Bike sharing: A review of evidence on impacts and processes of diffusion and implementation. *Research in Transportation Business & Management*, *15*, 28-38. https://doi.org/10.1016/j.rtbm.2015.03.003
12. Goodman, A., & Cheshire, J. (2014). Inequalities in the London bicycle sharing system revisited: Impacts of extending the scheme to poorer areas of the city. *Journal of Transport Geography*, *41*, 272-279. https://doi.org/10.1016/j.jtrangeo.2014.04.004
13. Murphy, E., & Usher, J. (2012). The role of bicycle-sharing in the city: Analysis of the Irish experience. *International Journal of Sustainable Transportation*, *9*(2), 116-125. https://doi.org/10.1080/15568318.2012.748855
14. INRIX. (2024). *2023 Global Traffic Scorecard*.
15. City of Austin. (n.d.-a). *All Ages and Abilities Bicycle Network*. ArcGIS StoryMaps.
16. City of Austin. (n.d.-b). *ATX Walk Bike Roll*.
17. City of Austin. (2019). *Austin Strategic Mobility Plan*.
18. City of Austin. (2012). *Imagine Austin Comprehensive Plan*.
19. Lipman, B. (2006). *A heavy load: The combined housing and transportation burdens of working families*. Center for Housing Policy.
20. Capital Metro. (2024a). *Interlocal Agreement Between the City of Austin and Capital Metropolitan Transportation Authority Relating to Bicycle Share Program*.'
21. Capital Metro. (2021). *MetroBike Expansion Plan*.
22. Capital Metro. (2024b). *Resolution No. 20240125-050*. City of Austin.
23. Chardon, C. M., Caruso, G., & Thomas, I. (2017). Bicycle sharing system 'success' determinants. *Transportation Research Part A: Policy and Practice*, *100*, 202-214. https://doi.org/10.1016/j.tra.2017.04.020
24. Shaheen, S. A., Guzman, S., & Zhang, H. (2010). Bikesharing in Europe, the Americas, and Asia: Past, present, and future. *Transportation Research Record: Journal of the Transportation Research Board*, *2143*(1), 159-167. https://doi.org/10.3141/2143-20
25. Noland, R. B., Smart, M. J., & Guo, Z. (2016). Bikeshare trip generation in New York City. *Transportation Research Part A: Policy and Practice, 94,* 164–181. https://doi.org/10.1016/j.tra.2016.08.030
26. Zhang, Y., Thomas, T., Brussel, M., & van Maarseveen, M. (2017). Exploring the impact of built environment factors on the use of public bikes at train stations: Case study in

Zhongshan, China. *Journal of Transport Geography*, *58*, 59-70. https://doi.org/10.1016/j.jtrangeo.2016.11.014

27. Vandenbulcke, G., Degraeuwe, B., Meeusen, R. and Panis, L.I. (2011) Cycle Commuting in Belgium, Spatial Determinants and "Re-Cycling" Strategies. Transportation Research Part A: Policy and Practice, 45, 118-137.
28. Nodjomian, A. T., & Kockelman, K. M. (2019). How does the built environment affect interest in the ownership and use of self-driving vehicles? *Journal of Transport Geography, 78,* 115–134. https://doi.org/10.1016/j.jtrangeo.2019.05.016
29. Buck, D. D., & Buehler, R. (2012). Bike lanes and collisions in Washington, D.C. Transportation Research Record: Journal of the Transportation Research Board, 2314(1), 16-24.
30. Croci, E., & Rossi, D. (2014). *Optimizing the position of bike sharing stations*: *The Milan case*. SSRN. https://doi.org/10.2139/ssrn.2461179
31. He, Y., Song, Z., Liu, Z., & Sze, N. N. (2019). Factors influencing electric bike share ridership: Analysis of Park City, Utah. Transportation Research Record: Journal of the Transportation Research Board, 2673(5), 414–425. 1 https://doi.org/10.1177/0361198119838981
32. Guidon, S., Wicki, M., Bernauer, T., & Axhausen, K. W. (2020). Transportation service bundling – For whose benefit? Consumer valuation of pure bundling in the passenger transportation market. Transportation Research Part A: Policy and Practice, 131, 74–94. https://doi.org/10.1016/j.tra.2019.09.023
33. Hampshire, R. C., & Marla, L. (2012). An analysis of bike sharing usage: Explaining trip generation and duration. *International Journal of Sustainable Transportation*, *6*(5), 319-339.
34. Faghih-Imani, A., Eluru, N., El-Geneidy, A. M., Rabbat, M., & Haq, U. (2014). How land-use and urban form impact bicycle flows: Evidence from the bicycle-sharing system (BIXI) in Montreal. Journal of Transport Geography, 41, 306-314. https://doi.org/10.1016/j.jtrangeo.2014.01.013
35. Faghih-Imani, A., Hampshire, R., Marla, L., & Eluru, N. (2017). An empirical analysis of bike sharing usage and its potential impact on public transit. *Transportation Research Part A: Policy and Practice*, *99*, 56-70. https://doi.org/10.1016/j.tra.2016.12.007
36. Lin, D., Zhang, Y., Zhu, R., & Meng, L. (2019). The analysis of catchment areas of metro stations using trajectory data generated by dockless shared bikes. *Sustainable Cities and Society, 49,* 101598. https://doi.org/10.1016/j.scs.2019.101598
37. Kabak, M., Erbaş, M., Cetinkaya, C., & Özceylan, E. (2018). A GIS-based MCDM approach for the evaluation of bike-share stations. *Journal of Cleaner Production*, *201(10)*, 49-60. https://doi.org/10.1016/j.jclepro.2018.08.033
38. MacArthur, J., Cherry, C., Harpool, M., & Scheppke D. (2018). A North American Survey of Electric Bicycle Owners. NITC-RR-1041. Portland, OR: *Transportation Research and Education Center (TREC),* https://doi.org/10.15760/trec.197
39. Guo, Y., & He, S. Y. (2020). Perceived built environment and dockless bikeshare as a feeder mode of metro. Transportation Research Part D: Transport and Environment, 88, 102693. https://doi.org/10.1016/j.trd.2020.102693
40. Martens, K. (2004). The bicycle as a feedering mode: experiences from three European countries. *Transportation Research Part D: Transport and Environment*, *9*(4), 281-294. https://doi.org/10.1016/j.trd.2004.02.005

41. Martens, K. (2007). Promoting bike-and-ride: The Dutch experience. *Transportation Research Part A: Policy and Practice*, *41*(4), 326-338. https://doi.org/10.1016/j.tra.2006.09.010
42. Basu, R., & Ferreira, J. (2021). Shifting Gears: Heterogenous Effects of Bike-Sharing Platforms on City Bus Ridership Demand. https://doi.org/10.1016/j.trd.2021.102721
43. Martin, E., & Shaheen, S. A. (2014). Evaluating the impacts of bike sharing on transportation and health. *Access Magazine*, *1*(44), 22-27. https://doi.org/10.1016/j.jtrangeo.2014.06.026
44. Mix, R., Hurtubia, R., & Raveau, S. (2022). Optimal location of bike-sharing stations: A built environment and accessibility approach. *Transportation Research Part A: Policy and Practice*, *160*, 126-142. https://doi.org/10.1016/j.tra.2022.03.022
45. Ji, S., Liu, X., & Wang, Y. (2024). The role of road infrastructures in the usage of bikeshare and private bicycle. *Transport Policy, 147*, 171–183. https://doi.org/10.1016/j.tranpol.2024.01.020
46. Ethier, B. G., Wilson, J. S., Camhi, S. M., Shi, L., & Troped, P. J. (2024). An analysis of built environment characteristics in daily activity spaces and associations with bike share use. Travel Behaviour and Society, 37, 100850. https://doi.org/10.1016/j.tbs.2024.100850
47. Fishman, E., Washington, S., Haworth, N., & Watson, A. (2015b). Factors influencing bike share membership: An analysis of Melbourne and Brisbane. *Journal of Transport Geography*, *41*, 1-12. https://doi.org/10.1016/j.tra.2014.10.021
48. Shaheen, S. A., Cohen, A., & Martin, E. (2013). Public bikesharing in North America. *Transportation Research Record: Journal of the Transportation Research Board, 2387*(1), 83–92. https://doi.org/10.3141/2387-10
49. Böcker, L., Anderson, E., Uteng, T. P., & Throndsen, T. (2020). Bike sharing use in conjunction to public transport: Exploring spatiotemporal, age and gender dimensions in Oslo, Norway. *Transportation Research Part A: Policy and Practice*, *138*, 389-401. https://doi.org/10.1016/j.tra.2020.06.009
50. Nikitas, A. (2019). Gendered cycling participation: Examining the role of bike sharing in the United States. *Sustainability*, *11*(11), 3206. https://doi.org/10.3390/su11113206
51. Ogilvie, D., & Goodman, A. (2012). Inequalities in usage of a public bicycle sharing scheme: Socio-demographic predictors of uptake and usage of the London cycle hire scheme. *Preventive Medicine*, *55*(1), 40-45. https://doi.org/10.1016/j.ypmed.2012.05.002
52. Campbell, A. A., Cherry, C. R., Ryerson, M. S., & Yang, X. (2016). Factors influencing the choice of shared bicycles and shared electric bikes in Beijing. Transportation Research Part C: Emerging Technologies, 66, 1–11. https://doi.org/10.1016/j.trc.2016.03.004
53. DeMaio, P. (2009). Bike-sharing: History, impacts, models of provision, and future. *Journal of Public Transportation*, *12*(4), 41-56. https://doi.org/10.5038/2375-0901.12.4.3
54. Dill, J., Ma, J., McNeil, N., Broach, J., & MacArthur, J. (2022). Factors influencing bike share among underserved populations: Evidence from three 1 U.S. cities. Transportation Research Part D: Transport and Environment, 113, 103471. https://doi.org/10.1016/j.trd.2022.103471
55. McNeil, N., Dill, J., MacArthur, J., Broach, J., & Howland, S. (2017). Breaking barriers to bike share: Insights from residents of traditionally underserved neighborhoods (Report No. NITC-RR-884b). Transportation Research and Education Center (TREC). https://doi.org/10.15760/trec.176

56. Kodransky, M., & Lewenstein, G. (2014). *Connecting low-income people to opportunity with shared mobility*. Institute for Transportation and Development Policy.
57. Stewart, S. K., Johnson, D. C., & Smith, W. P. (2013). Bringing bike share to a low-income community: Lessons learned through community engagement. *Preventing Chronic Disease, 10*, E138. 1 https://doi.org/10.5888/pcd10.120274
58. Setterfield, E. (2016). *Bike share equity analysis: A look at bike share programs across the United States*. University of Oregon.
59. Qian, X., & Jaller, M. (2020). Bikesharing, equity, and disadvantaged communities: A case study in Chicago. *Transportation Research Part A: Policy and Practice, 140*, 354–371. https://doi.org/10.1016/j.tra.2020.07.004
60. Fazio, M., Giuffrida, N., Le Pira, M., Inturri, G., & Ignaccolo, M. (2020). Bike oriented development: Selecting locations for cycle stations through a spatial approach. Research in Transportation Business & Management, 36, 100576. https://doi.org/10.1016/j.rtbm.2020.100576
61. García-Palomares, J. C., Gutiérrez, J., & Latorre, M. (2012). Optimizing the location of stations in bike-sharing programs: A GIS approach. *Applied Geography*, *35*(1-2), 235-246. https://doi.org/10.1016/j.apgeog.2012.07.002
62. Faghih-Imani, A., & Eluru, N. (2016). Incorporating the impact of spatial correlations on bicycle sharing system demand: A grouped random parameters hierarchical negative binomial regression approach. *Transportation Research Part A: Policy and Practice*, *94*, 199-214. https://doi.org/10.1016/j.jtrangeo.2016.06.008
63. Larsen, J. (2013). Bike-sharing programs hit the streets in over 500 cities worldwide. Earth Policy Institute.
64. Banerjee, A., Geddes, J. R., & Greaves, S. P. (2020). Investigating the determinants influencing the demand and redistribution requirements for dockless bike sharing systems. *Transportation Research Part A: Policy and Practice*, *142*, 163-182. https://doi.org/10.1016/j.trip.2020.100101
65. Conrow, L., Murray, A. T., & Fischer, H. A. (2018). An optimization approach for equitable bicycle share station siting. *Journal of Transport Geography, 69*, 163-170. https://doi.org/10.1016/j.jtrangeo.2018.04.011
66. Wuerzer, T., McClung, S., Kubiske, W., & Lowry, M. (2012). *Optimal bike share station location model for Boise State University*. Boise State University ScholarWorks.
67. Qian, X., & Jaller, M. (2021). Bikeshare destination choices and accessibility among disadvantaged communities. *Transportation Research Part D: Transport and Environment, 91,* 102686. https://doi.org/10.1016/j.trd.2020.102686
68. Hasan, S. M. (2016). *Equitable access to bike sharing systems: A case study of Divvy bike sharing system in Chicago* [Master's thesis, Western Michigan University]. ScholarWorks at WMU.
69. National Association of City Transportation Officials (NACTO). (2015). *Bike Share Station Siting Guide*.
70. Shu, J., Chou, M. C., Liu, Q., Teo, C.-P., & Wang, I-L. (2013). Models for effective deployment and redistribution of bicycles within public bicycle-sharing systems. *Operations Research*, *61*(6), 1346–1359. https://doi.org/10.1287/opre.2013.1215
71. Auld, J., Mohammadian, A. K., & Semoga, K. N. (2016). POLARIS: Agent-based modeling framework development and implementation for integrated microscopic–

mesoscopic transport simulation. *Transportation Research Part C: Emerging Technologies*, *65*, 100-115. https://doi.org/10.1016/j.trc.2015.07.017

72. Fakhrmoosavi, F., Dean, K. S., Gurumurthy, K. M., & Kockelman, K. M. (2024). *Shared autonomous electric vehicle (SAEV) fleet operations and charging strategies: Sensitivity analysis for Austin, Texas*. https://doi.org/10.1061/JTEPBS.TEENG-7955
73. Huang, Y., Gurumurthy, K. M., Kockelman, K. M., & Verbas, O. (2021). *Shared Autonomous Vehicle Fleets to Serve Chicago's Public Transit*.
74. Dean, K. S., Fakhrmoosavi, F., Gurumurthy, K. M., & Kockelman, K. M. (2022a). *Off-street parking of shared automated vehicles: Predictions for Chicago using agent-based simulation*. https://doi.org/10.1061/JTEPBS.TEENG-7955
75. Dean, M. D., Gurumurthy, K. M., de Souza, F., Auld, J., & Kockelman, K. M. (2022b). Synergies between repositioning and charging strategies for shared autonomous electric vehicle fleets. *Transportation Research Part D: Transport and Environment*, *109*, 103314. https://doi.org/10.1016/j.trd.2022.103314
76. Bateman, L. B., Smith, C. S., DiPietro, B., & Stone, B. (2021). Barriers and facilitators to bikeshare programs: A qualitative study in an urban environment. *Journal of Transport & Health*, *21*, 101043. https://doi.org/10.1016/j.jth.2021.101062
77. Kim, G., Park, S., & Lee, S. (2025). How do directed and undirected travel differ? Evidence from year-long bikeshare trips. *Transportation Research Part D: Transport and Environment, 142,* 104713. https://doi.org/10.1016/j.trd.2025.104713
78. Yang, X., Wang, Y., & Chen, M. (2024). Where do built environment attributes most effectively influence bike sharing usage? Evidence from Richmond, Virginia. *ISPRS International Journal of Geo-Information*, *13*(5), 144. https://www.researchgate.net/publication/390493102_Where_do_built_environment_attributes_most_effectively_influence_bike_sharing_usage
79. Willberg, E., Salonen, M., & Toivonen, T. (2021). What do trip data reveal about bike-sharing system users? *Journal of Transport Geography*, *91*, 102971. https://doi.org/10.1016/j.jtrangeo.2021.102971
80. National Association of City Transportation Officials (NACTO). (2020). *Shared Micromobility in the U.S.: 2019*.
81. National Household Travel Survey (NHTS). (2023). *2022 National Household Travel Survey*. U.S. Department of Transportation, Federal Highway Administration.
82. Arellana, J., Saltarín, M., Larrañaga, A. M., Alvarez, V., & Henao, C. A. (2020). Urban commuting challenges: An analysis of usability, accessibility, and transport sustainability for bike-sharing systems. *Sustainability*, *12*(10), 4156. https://doi.org/10.1016/j.tra.2020.07.010
83. Capital Metropolitan Transportation Authority. (2024). *Approved FY2025 operating and capital budget*.
84. Clockston, C., & Rojas-Rueda, D. (2021). Health impacts of bike-sharing systems in the U.S. *Environmental Research*, *202*, 111709. https://doi.org/10.1016/j.envres.2021.111709
85. Capital Bikeshare. (2011). *Capital Bikeshare 2011 survey executive summary*.