HHS Public Access
Author manuscript
J Transp Geogr. Author manuscript; available in PMC 2020 January 01.

Published in final edited form as:
J Transp Geogr. 2019 January ; 74: 91–96. doi:10.1016/j.jtrangeo.2018.11.009.

Freedom from the Station: Spatial Equity in Access to Dockless Bike Share

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Abstract

Background: Bike sharing systems have potential to substantially boost active transportation levels (and consequent physical and mental health) in urban populations. We explored equity of spatial access in a novel ‘dockless’ bike share system that does not that constrain bike pickup and drop-off locations to docking stations.

Methods: Starting in July 2017, Seattle, Washington piloted a dockless bike share system that made 10,000 bikes available. We merged data on resident sociodemographic and economic characteristics from the American Community Survey about 93 defined neighborhoods with data about bike locations, bike idle time, and which neighborhoods operators rebalanced bikes to. We used mapping and descriptive statistics to compare access between neighborhoods along sociodemographic and economic lines.

Results: With many bikes available, no neighborhood was consistently excluded from access. However, the average availability ranged from 3 bikes per day to 341 per day. Neighborhoods with more bikes had more college-educated residents (median 75% college-educated vs. 65%) and local community resources (median opportunity index score of 24 vs. 19), and higher incomes (median 83,202 vs. 71,296). Rebalancing destinations were strongly correlated with neighborhood demand (r=0.61).

Conflicts of Interest: no conflicts of interest to disclose.

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Conclusions: The overall scale of the dockless system ensured there was baseline access throughout Seattle. We observed modest inequities in access along sociodemographic lines, similar to prior findings in studies of docked bike share systems. Dockless bike share systems hold promise for offering equitable spatial access to bike sharing.

1. Introduction

Bike share systems hold the potential to improve health, both directly through increased physical activity and indirectly as reduced travel times and costs increase access to opportunities throughout a city (Ricci, 2015; Shaheen et al., 2010). However, inequitable access to share bikes may restrict these benefits to the subpopulations with access, which may exacerbate disparities within a city. In many North American cities with bike share programs, bike share users are disproportionately Non-Hispanic White, employed, and have higher incomes and educations (Fishman, 2016; Ricci, 2015; Shaheen, 2012).

One barrier to uptake among disadvantaged populations has been geographic coverage. Across North American cities, bike share docking stations tend to be located in more advantaged neighborhoods (Smith et al., 2015; Ursaki and Aultman-Hall, 2016). In an assessment of 35 bike share systems across the US, 53% of docking stations were located in the top quintile of economically advantaged census block groups (Smith et al., 2015). Similarly, an evaluation of seven bike share programs found less access to bike share programs among less educated and lower income populations (Smith et al., 2015). As of 2016, four of five Canadian bike share systems provide better access for advantaged areas (Hosford and Winters, 2018).

However, to our knowledge, all bike share systems previously studied with respect to spatial equity have been ‘docked’ systems, wherein bikes must be returned to a docking station. Recently, ‘dockless’ (sometimes also called ‘free-floating’ or ‘flexible’) bike share technology has been developed, allowing users to use a mobile app to unlock and lock GPS-enabled share bikes anywhere in the city when their rides are completed (Pal and Zhang, 2017; Reiss et al., 2015). Dockless systems have boomed in popularity in China (Sin, 2017), and in Spring 2017, two American companies, Spin (www.spin.pm) and LimeBike (www.limebike.com), launched similar systems in the United States. As of May 2018, dockless bike share systems are in 28 U.S. cities including Seattle, Austin, and Washington, DC (NACTO, 2018), and are being considered in many others (NABSA, 2017), with varying degrees of public and political support. In the fast-changing small-scale mobility industry, these dockless systems represent a timely area for equity research.

Several aspects of dockless systems suggest their equity profile may vary from that of docked systems. On one hand, without docking stations anchoring the end points of rides, bikes may naturally accrete in locations where the relatively privileged populations using bike shares work and live due to natural supply and demand patterns. On the other, because dockless systems do not incur the infrastructure costs of building docking stations (whose costs range from $30,000-$50,000 per docking station (Shaheen et al., 2014)), these systems have a lower cost per bike and have launched with many more bikes per resident than dock-based systems (Kroman, 2018). It may be that these large numbers are sufficient to achieve universal access. Finally, ‘rebalancing’, wherein bike share operating companies (hereafter operators) move bikes that have remained idle to locations where they are more likely to be ridden, may increase or decrease equity of spatial access depending on where bikes remain idle and where they are rebalanced to.

In July 2017, the City of Seattle, Washington’s Department of Transportation (SDOT) launched a pilot program to allow dockless bike share companies to operate in the city under a permit. Three operators (LimeBike, Spin, and Ofo) launched programs shortly thereafter. We assessed the equity of spatial access to bike share bikes during the first six months of this pilot program using publicly available aggregated data.

2. Materials and Methods

2.1 Setting

Seattle is a mid-sized city in Washington State, USA, with an estimated 724,745 residents as of 2017, the most recent year for which American Community Survey estimates are available. Seattle has a robust bicycling community and is among the top American cities for bicycling to work (McKenzie, 2014). While the city is hilly and has a rainy season that typically extends from October to June, it also has relatively mild winters (daytime temperatures rarely drop below freezing) and few days with heavy rainfall (average yearly precipitation is lower than that of most US cities East of the Mississippi). From October 2014 through March 2017, Seattle had a small (500-bike, 50-station), publically owned docked bike share system with limited spatial access (5). This docked bike share program had relatively low ridership (<1 trip per bike per day); the reasons for its being discontinued are controversial.

2.1.1 Dockless Bike Share—In summer 2017, three operators launched dockless bike share programs in Seattle as part of SDOT’s pilot. Operators offered smartphone applications allowing users to rent a bike for $1–2/hour (nominal costs varied by provider, and each offered free ride incentives during the pilot period). Users were permitted to ride anywhere in the city and instructed to lock and leave bikes in public locations (e.g. on the space between sidewalk and curb). Within 6 months of launching, 10,000 bikes were available, over 450,000 trips had been taken, and roughly 1/3 of adults with internet access in the city reported taking at least one ride (City of Seattle, 2018). Over 137,000 user accounts had been created, though because these accounts are aggregated across the three operators for privacy reasons, there is no way to tie accounts to individuals and it is therefore unclear how many people these accounts represent.

2.1.2 Bike Usage—The pilot program required operators to provide data to the Transportation Data Collaborative (TDC) operated by the University of Washington, including time, anonymized user identification, origin, and destination for each trip. The TDC is charged with ensuring the privacy of the individuals represented in this dataset beyond what anonymization alone can provide, and as a result the raw data are protected from public release. However, the TDC also provides periodic reports to the Seattle Department of Transportation (SDOT) for permit enforcement and transparency purposes. The TDC submitted an initial report to SDOT covering the initial six months of operation summarizing system usage (City of Seattle, 2018). We used the data provided as part of this report to perform this study.

2.1.3 Neighborhoods—In the TDC report, location measures were aggregated to one of 93 neighborhoods. Neighborhoods ranged in size from 0.2 km^2 to 6.8 km^2 and were selected by SDOT to maximize interpretability for city residents. Considerations included perceived neighborhood boundaries, consistency of land uses within neighborhoods, and city topography. Smaller neighborhoods tended to be more densely populated: for example, the 6.8km^2 neighborhood is an industrial area that includes large warehouses and relatively few residents.

2.1.4 Population Measures—For each neighborhood, we acquired 2016 American Community Survey (ACS) 5-year estimates of various social and economic factors used in prior work on docked bike share equity, including income, age, and educational attainment (City of Seattle, 2018). We also used these ACS data to compute each neighborhood's USA today diversity index score as a measure of racial/ethnic diversity: This score is scaled from 0 to 100, where lower scores represent higher probabilities that two people randomly selected from the same neighborhood will report the same census-defined racial/ethnic group (Meyer and McIntosh, 1992). We used proportional allocation to account for mismatches between tract boundaries and neighborhood boundaries.

After discussions with SDOT planners, we incorporated two composite equity measures from Seattle's comprehensive plan (City of Seattle, 2016): (a) displacement risk index and (b) access to opportunity index. The displacement risk index assesses risk of gentrification-related housing displacement and includes measures of demographics (e.g. race, linguistic isolation), housing (e.g. housing cost burden, median rent), and spatial characteristics (e.g. proximity to core businesses). The access to opportunity index assesses local community resources and includes measures such as bus stops, light rail, parks, and community centers. Both indices were constructed by first categorizing component measures and then summing the category indicators, such that higher scores indicate higher displacement risk and more access to resources, respectively. From raster surfaces (geospatial data files with values computed for each point on a 200 foot square grid covering the city) of each measure developed by Seattle's Office of Planning and Community Development, we computed mean values for each neighborhood.

2.1.5 System Data—Aggregated neighborhood bike share usage measures across all operators were taken from the TDC report and included: (a) number of bikes available in each neighborhood on each day, (b) average number of days each bike remained idle in each neighborhood, (c) average number of bikes rebalanced (i.e. moved to the neighborhood by the operator rather than by a user ride) to each neighborhood each day.

3.1 Theory/Calculation

3.1.1 Equity in Spatial Access—Prior work on bike share access has used the presence of a docking station in an area as an indictor of access (Hosford and Winters, 2018; Ursaki and Aultman-Hall, 2016). There is no directly analogous measure for Seattle's dockless system because bikes need not be left at docks. We operationalized spatial access to bike share for a neighborhood as the average number of bikes available per resident per day. For analysis, we grouped neighborhoods as above or below the median bike availability over the 6-month period. The median neighborhood had about one bike per 263 residents per day over the trial period. Bike availability by neighborhood varied somewhat over the 6-month trial – for example, more bikes were available near the University of Washington campus during the period when classes were in session, and availability across the city generally increased as the pilot progressed – but there was not a clear pattern of dramatic change in availability that would preclude use of an average over the time period. In sensitivity analyses, we tested the robustness of our findings by comparing the highest quartile of availability to the lowest quartile of availability, rather than above and below the median.

3.1.2 System Analysis—Our descriptive analysis of equity in access compared each neighborhood-level demographic measure in relation to bike availability. First, we plotted bike availability compared with each demographic measure. Next, we used two-tailed Wilcoxon rank-sum tests at a significance level of $\alpha=0.05$ to assess statistical significance of observed differences in bike availability by neighborhood-level demographic measure.

We augmented this analysis of equity in access with an analysis of equity in rebalancing (i.e. instances where operators moved bikes to new neighborhoods). The principle underlying this analysis is that, in addition to ensuring every neighborhood has a baseline level of access, an equitable bike share system would redistribute bikes proportional to their probability of being ridden, independent of neighborhood characteristics (i.e. operators would not systematically fail to rebalance bikes to meet demand in less advantaged neighborhoods).

For this analysis, we defined demand as the inverse of idle time (e.g. a neighborhood with an average idle time of 0.5 days/bike had an estimated demand of 2 bikes/day). Then, we considered average number of bikes per day rebalanced to a given neighborhood to represent that neighborhood's rebalancing priority, and considered supply in excess of demand to be the average number of days a bike parked in the neighborhood remained idle. Thus, neighborhoods with shorter idle times might be considered undersupplied relative to neighborhoods with longer idle times, even though each has some bike share bikes present. Next, we divided neighborhoods into tertiles based on demand and rebalancing. We considered neighborhoods "underserved" if they were in the top tertile of demand and the bottom tertile of rebalancing, and "overserved" if in the bottom tertile of demand and the top tertile of rebalancing. We then explored geographic and demographic contrasts and similarities between overserved and underserved neighborhoods.

Spatial and statistical analyses were performed in R for Windows 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria).

4. Results

4.1 Availability

While bike availability varied greatly between the 93 neighborhoods (Figure 1, Panel A), no neighborhood was consistently denied access to bike share bikes during the trial period (average bikes available per day ranged from 3 in Arbor Heights in the far south end to 341 in Belltown in the center city). There were trends towards more bike availability in socioeconomically advantaged locations: neighborhoods above the median bike availability level had higher median incomes (an average of 83,202 as compared with 71,296), more college-educated residents (75% in high availability neighborhoods as compared with 65% in low availability neighborhoods, Figure 1, Panel B), and more access to opportunity on average, though no neighborhood measure showed a very strong pattern indicating inequity (Table 1, Supplementary Figure 1). Comparing neighborhoods in the lowest quartile of bike availability to those in the highest quartile showed similar patterns to above and below the median, though the income differential was somewhat more extreme (Supplementary Table 1).

4.2 Idle times and Rebalancing

Average idle times were highly variable between neighborhoods, ranging from an average of 0.8 days idle to an average of 6.5 days idle. Rebalancing was similarly variable, ranging from an average of 1.0 bikes rebalanced to the neighborhood each day to 72.9, and negatively correlated with idle time (spearman $r=-0.61$) No single neighborhood had high demand and very low rebalancing or low demand and very high rebalancing (Figure 2, Panel A). Using tertiles to classify neighborhood by demand and rebalancing, we identified only two of the ninety-three neighborhoods (Broadway and West Queen Anne, which are both high-density, hilly, and mostly residential neighborhoods near the urban core) as having higher idle times than similarly well-served neighborhoods. We also identified only two neighborhoods (Pinehurst and Victory Heights, both neighborhoods with little bike or pedestrian infrastructure near the north border of the city) as underserved by rebalancing efforts. All four of these neighborhoods (highlighted in Figure 2, Panel B) are majority non-Hispanic white. None are in the top or bottom 10% of neighborhood incomes: West Queen Anne is in the highest income quartile (ranked 80th of the 93 neighborhoods), Pinehurst is in the lowest (ranked 16th) and Victory Heights, and Broadway are modestly below the median (29th and 31st respectively).

5. Discussion

To our knowledge, this analysis of Seattle, WA's six-month bike share pilot program is the first analysis of the spatial equity of a dockless bike share system. The low per-bike cost of the dockless system afforded a 10,000-bike system (in contrast to the prior 500-bike docked system) providing access throughout the city. Despite this broad base of access, many more bikes per capita were available in some neighborhoods than others. Neighborhoods with more bikes tended to have shorter idle times and were slightly more socioeconomically privileged on average, though the key driver of where operating companies moved bikes was to increase supply in neighborhoods with short idle times. We did not detect significant disparities in racial/ethnic composition or risk of displacement between neighborhoods that had more or less access to share bikes.

With respect to education, our results are concordant with prior findings regarding spatial equity in bike share dock placement. In a study of docked bike share systems in 7 US cities (including Seattle's previous system), in each city, a greater proportion of residents of areas where docks were present had college degrees than did residents of areas where docks were not present (Ursaki and Aultman-Hall, 2016). Similarly, a study of docked systems in Canada found that in 4 of 5 cities, stations were disproportionately in areas scoring lower on a deprivation index including low education as a marker of disadvantage (Hosford and Winters, 2018). Likewise, we found greater bike availability in neighborhoods with more college-educated residents.

We caution, though, that our results are not directly comparable to prior work. First, because the sheer number of bikes available in Seattle was comparable to the number available in New York, a city more than 10 times Seattle's population (City of Seattle, 2018; Ursaki and Aultman-Hall, 2016), bikes were available throughout the city. Second, because prior work focused on the presence of a dock rather than the number of bikes available in each dock over the study period, prior work represents *potential* spatial access whereas the present analysis, leveraging bike-specific data, represents *realized* access.

Our study has several key strengths. First, to the best of our knowledge, this work is the first to study the equity implications of dockless bike share. Because dockless systems do not incur the cost of installing docking stations, they are able to provide access to a much larger portion of the city than docked systems typically have, including Seattle's prior system, which was geographically limited. Second, thanks to the data collation efforts of TDC, we were able to study all three bike share systems together, allowing a robustness that an analysis of a single system would not. Third, as noted above, our analysis covered realized spatial access (bikes actually being present in a location), rather than potential spatial access (dock location for a bike).

However, our results should be interpreted in light of several limitations. First, all spatial information about bike usage were as reported by GPS devices on board the bikes themselves. These data have limitations common to GPS-based spatial research, including error related to slow startup time and differential error by context (Mooney et al., 2016; Schipperijn et al., 2014). Second, owing to privacy and data access policies, our analysis was limited to publicly reported neighborhood aggregates. Such analyses of spatially aggregated individual data are vulnerable to the modifiable areal unit problem (Fotheringham and Wong, 1991) – that is, that different units of spatial aggregation lead to different analytic results. Third, our measure for spatial access (bikes per resident) accounts for population size but not neighborhood size, which varied from $0.2km^2$ to $6.8km^2$. Future analyses leveraging trip-specific data about start locations may improve measures of access. Fourth, our indicator of neighborhood demand, the amount of time the average bike in a given neighborhood remains idle, is a simplification of the potentially nuanced decision to ride a bike share bike. For example, a bike at the bottom of a hill in a given neighborhood may be substantially less desirable than a bike at the top of a hill in the same neighborhood. Future analyses leveraging trip-specific data and population-based surveys may improve estimates of demand. Fifth, the dockless program was limited to Seattle, where cycling is common relative to other cities in the US (McKenzie, 2014). Cycling is becoming more common across the country as cities invest in active transportation infrastructure (Mooney, et al., 2018); nonetheless, city-specific factors including cycling prevalence and infrastructure may have affected dockless bikeshare usage patterns. Finally, our analysis considered only the spatial access component of equity. Other aspects of equity, including cost-related barriers, differential community outreach, and options for users without smartphones, are important aspects of an equitable bike share program (McNeil et al., 2018), and are a key area for future research.

6. Conclusions

In conclusion, we analyzed the spatial equity of access to dockless share bikes provided by three operators in a pilot program in Seattle, WA. Such dockless programs are novel in the fast-changing small-scale mobility industry, and a timely area for equity research. We found more bikes to be available in neighborhoods with slightly higher incomes and more access to community resources on average, though we did not find disparities by racial/ethnic composition or risk of displacement. These results are encouraging for policymakers considering dockless systems in their communities. Future research should focus on other aspects of equity and on the role of rides and rebalancing as a contributor to spatial equity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was supported by a research grant of the Better Bike Share Partnership, a collaboration funded by the JPB Foundation in partnership with the City of Philadelphia, People for Bikes, the Bicycle Coalition of Greater Philadelphia Area, and National Association of City Transportation Officials (NACTO). The database and infrastructure for this project were funded by the Seattle Department of Transportation and the Washington State Transportation Center (TRAC) at the University of Washington.

The authors would like to thank Amy Auchincloss for helpful comments on a prior version of this manuscript, and to acknowledge Joel Miller of the Seattle Department of Transportation for his assistance interpreting the data.

SM received funding from National Institute of Child Health and Human Development (Grant 5T32HD057822-07) and the National Library of Medicine (Grant 1K99LM012868) and JH receives funding from the Urban Health Collaborative, Dornsife School of Public Health, Drexel University.

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Highlights

- Seattle’s dockless bikeshare pilot provided bikes to all neighborhoods in the city
- Neighborhoods with more educated residents had modestly more bikes
- Most bikes were rebalanced to neighborhoods with low bike idle times
- Seattle’s dockless systems has promising spatial equity characteristics

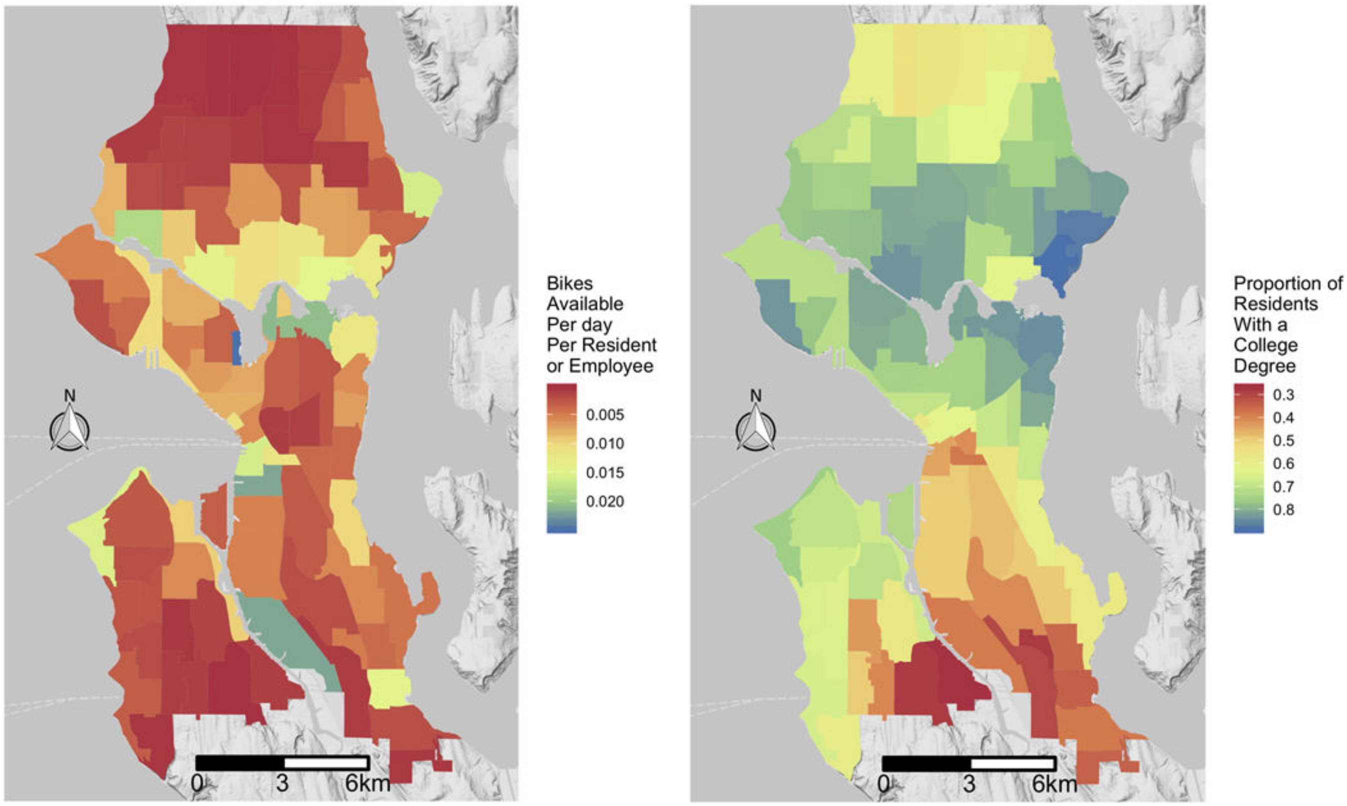

Figure 1:

Panel A) shows availability of bike share bikes by daily population for each neighborhood in Seattle in fall 2017. Panel B) shows the proportion of neighborhood residents who completed college, per the 2016 American Community Survey 5-year estimates

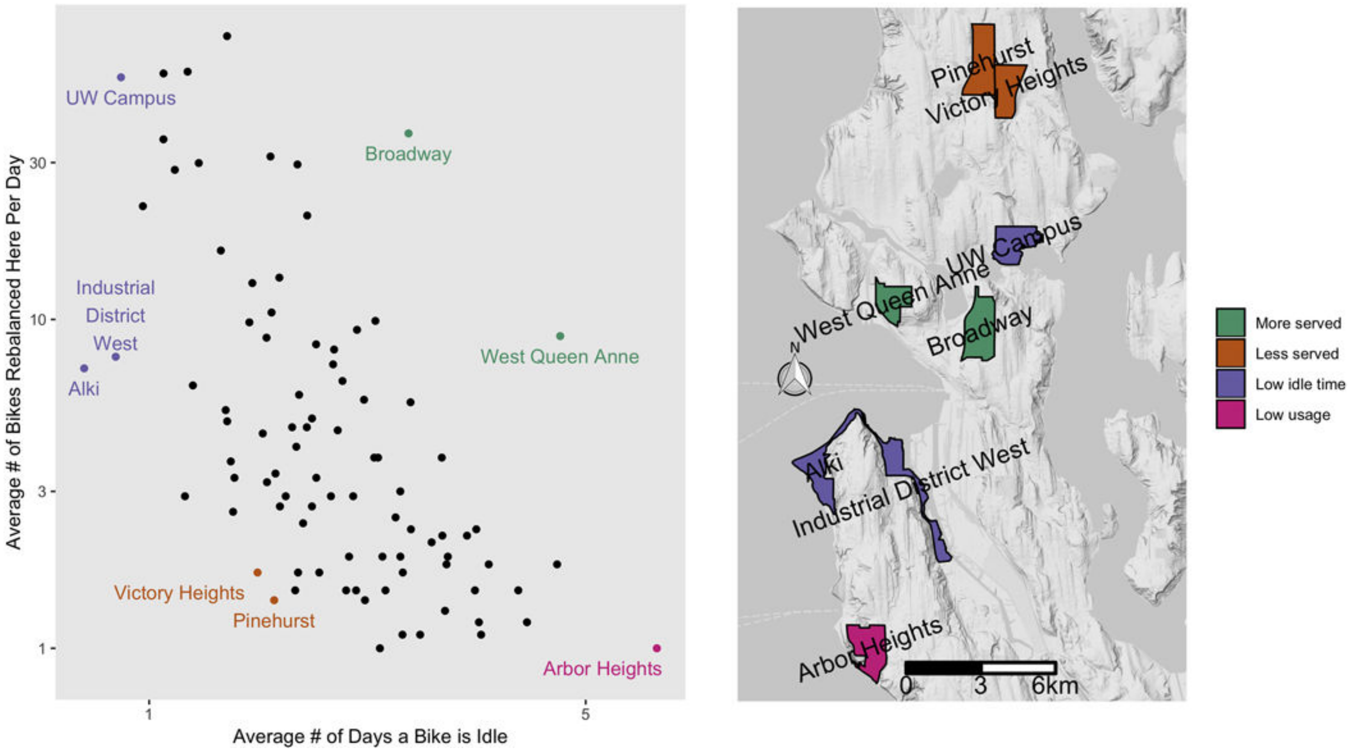

Figure 2:

Panel A) shows distribution of bikes rebalanced to a neighborhood as compared to average days bikes idle in that neighborhood (on the log scale), with selected neighborhoods highlighted for illustrative purposes. Panel B) highlights locations of these neighborhoods within the city overall.

Table 1:

Selected sociodemographic and economic characteristics of neighborhoods with above- and below- median bike share availability during a 6-month pilot in Seattle, WA in 2017 (n=93 neighborhoods)

	Frequency of Characteristic, Median % (IQR)	
Characteristic	**Low Bike Availability**[a]	**High Bike Availability**[b]
Population Density[c]	3049 (2246, 3704)	3190 (2153, 4256)
Over Age 60	18 (15, 22)	18 (15, 21)
Non-Hispanic White	67 (54, 78)	71 (54, 81)
Non-Hispanic Black	6 (2, 12)	2 (1, 10)
Non-Hispanic Asian	11 (7, 15)	12 (8, 19)
Any Hispanic	6 (5, 8)	5 (4, 7)
Diversity Index[d]	53 (38, 65)	48 (33, 64)
Income < $20,000	13 (8, 18)	10 (6, 16)
Income > $100,000	35 (27, 47)	41 (33, 48)
Income > $200,000	8 (5, 13)	12 (8, 20)
Median Household	71 296	83 202
Income (USD$)	(60 659, 92 561)	(67 589, 100 338)
High School Degree	96 (90, 97)	97 (90, 98)
College Degree	65 (55, 72)	75 (61, 81)
Displacement Risk[e]	14 (7, 18)	9 (7, 17)
Access to Opportunity[e]	19 (15, 23)	25 (20, 29)

[a]Below median number average of bikes available per resident

[b]Above median number average of bikes available per resident

[c]Median residents/km^2

[d]USAToday Diversity Index (CITE) . Range 0–100, where higher is more diverse

[e]Displacement Risk and Access to Opportunity from Seattle's comprehensive plan (13). Higher scores on the displacement risk index indicate higher risk of displacement. Higher scores on access to opportunity indicate greater access to resources.