High Impact Prioritization of Bikeshare Program Investment to Improve Underserved Communities' Access to Jobs and Essential Services

March 2018

A Research Report from the National Center for Sustainable Transportation

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National Center for Sustainable Transportation

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U.S. Department of Transportation (USDOT) Disclaimer

Acknowledgments

This study was funded by a grant from the National Center for Sustainable Transportation (NCST), supported by USDOT through the University Transportation Centers program. The authors would like to thank the NCST and USDOT for their support of university-based research in transportation, and especially for the funding provided in support of this project. We would like to thank sixteen experts that participated in our case study city selection: Susan Handy, Jennifer Dill, Alex Karner, Lisa Aultman-Hall, Dani Simons, Paul DeMaio, Sam Shelton, Heath Maddox, Kimberly Lucas, Darren Buck, Henry Dunbar, Jim Brown, Jeanie Ward-Waller, Steve Clark, Jennifer Donofrio, and Robb Davis.

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EXECUTIVE SUMMARY

Bikeshare programs are increasingly popular in the United States, and they are an important part of sustainable transportation systems. They offer an important alternative mode choice for many types of last mile trips. Most of the current research on bikeshare focuses on bikeshare benefits (e.g., how to replace auto trips with bike trips and reduce greenhouse-gas emissions) and bikeshare system management (e.g., bike repositioning between stations). Far less attention has been paid to the programmatic potential for providing greater access to jobs and essential services for underserved communities. To date, there is virtually no quantitative research aimed at designing bikeshare systems for underserved communities. We develop a new spatial index that identifies bikeshare station locations exhibiting a high potential for providing service for underserved communities. The index can: 1) facilitate the identification of priority areas for bikeshare investment based on current infrastructure and the potential for increased job or essential service access; 2) inform the siting of bikeshare stations and investment in bike infrastructure to better assist underserved populations, and finally 3) provide an estimate of the potential for improved job and social services access via bike-to-transit.

Introduction

Bikeshare systems, as a non-motorized transportation service, are a relatively recent mobility strategy offering access to a commonly shared bicycle. Members typically pick up a bicycle at a bicycle-docking station, returning the bicycle to any empty dock in proximity to the final destination. With the advent of successful bikeshare systems in Europe, a number of US cities, including Washington D.C., New York City, Chicago, and San Francisco to name just a few, have also seen bikeshare systems begin to flourish.

Reducing traffic congestion, improving physical health, and avoiding private bike theft are but a few of the considerable environmental and social benefits attributed to successful bikeshare systems [1-3]. But to date, the perception is that these benefits have largely accrued to a particular demographic segment. That is, existing bikeshare systems are typically aimed at users that tend to be white, affluent, and educated. Underserved communities[1] have largely been invisible when planning and implementing private bikeshare solutions.

In this research, we present a new method for identifying how bikeshare facilities might be spatially allocated to better serve low-income household and people of color with bikeshare systems. Using our new index, we then tested our hypothesis that existing bikeshare systems have been specifically designed to target certain ridership; ridership that does not include underserved communities. We find that locating stations in proximity to underserved communities have the potential to increase household access (by bike and by bike-to-transit) to essential services. We show that appropriately siting bikeshare facilities can close accessibility gaps between mobility constrained populations and critical services.

Background

As of 2014, there were 38 bikeshare systems across the US, the majority of which have adopted self-serve kiosk systems [4]. Most of the bikeshare systems in the US are operated by for-profit companies. For example, Motivate operates bikeshare systems in the San Francisco Bay Area (CA), Boston (MA), Chattanooga (TN), and Chicago (IL), while B-Cycle runs bikeshare systems in Los Angeles (CA), Philadelphia (PA), Miami (FL). Most of the larger bikeshare systems are located on the west and the northeast, with as many as 153,571 bikeshare trips occurring in Chicago, 245,530 in Washington D.C. and 726,400 in New York in March, 2017 [5].

Bikeshare usage tends to be highly correlated with population density [6, 7], income [8], non-white population [8], education [8], weather conditions [9], and whether bike stations are adjacent to bike lanes [7]. As a way of ensuring profitability, bikeshare operations have targeted

[1] Underserved communities may differ from the average population by attributes such as race, income, or age, or by the environment around them. The definition of underserved communities will vary between different fields of studies, but for the purpose of this research, underserved communities will refer to as people of color, low-income households, and transit-dependent households.

populations more likely to use the service, typically, male, white, younger, employed, affluent, educated and those more likely to be already engaged in cycling independent of bikeshare [10, 11]. Looking at Washington DC's Capital Bikeshare (CaBi) demographics, for example, indicates the predominant users are white and high income [12]. Only 19% of annual CaBi members are non-white and riders with an annual income of less than $50,000 make up only 24% of CaBi members [12]. This situation reflects a need for more equitable access to bikeshare system [12].

A variety of methodologies have been used to optimize the placement of bikeshare stations [13-16]. Most of these are based on objective functions using operation cost and/or service levels (measured by the availability rate and coverage of the respective origins and destinations). In practice, bikeshare stations are usually placed in areas of high attractions' rates (e.g. shopping centers, transit stations) and/or sidewalks are adjacent to bike lanes [17]. The issue of inequity with respect to bikeshare location placement has not been deeply examined in either research or practice.

There are also other barriers beyond profitability to increasing bikeshare access for underserved communities. And to be clear, by underserved we mean those communities whose transportation needs have been, either intentionally or unintentionally, overlooked [18]. The barriers faced by these populations can be roughly organized into four main factors. The first, a cultural divide, arises because many in underserved communities think of bikeshare as a transport mode for high income, high education level people and tourists [19-21]. Second, the lack of financial resources such as credit cards or membership fees inhibits an active use of bikeshare systems [22]. Third, physical barriers such as the absence of docking stations within walking distance [21], or the unavailability of something as simple as a bike helmet [22] or a phone that can provide bikeshare real-time information [19, 22] can present a barrier. Finally, the lack of adequate insurance coverage can create additional anxiety about the safety issues, e.g., cycling on roads [11, 23].

While there is little empirical data on cycling behavior of residents in underserved communities, a few correlations have been drawn based on certain types of trip making activity. McDonald found that children from low-income and people of color groups, particularly blacks and Hispanics, are potentially more likely to use active travel modes to attend school than whites or higher-income households when considering the combined effect of household income, vehicle access, the distance between home and school, and residential density [24]. Because of this, it is reasonable to assume that there may be a strong likelihood for children in low-income and people of color groups to use cycling as a primary mode to school. However, there are other important barriers to increasing bike trips that must be mitigated. For example, personal safety is often stated as a barrier to becoming more physically active [11, 25-27].

For bikeshare systems to prove useful to underserved communities, the way in which they are designed must shift from operationalizing systems that target certain demographics to designing systems that target gaps in accessibility. Identifying high impact bikeshare systems requires accounting for the complexities of how underserved populations currently access essential services and acknowledging that the actual travel behavior forming the basis for these trips is constrained by factors that have not been well studied.

Methods

We began our study by identifying bikeshare systems currently in operation in larger urban areas. The Pedestrian and Bicycle Information Center provides resources on existing bikeshare programs within the US [28] and from these data, we selected 34 candidate cities. For each of our candidate cities, we assembled data including city area (urbanized area in square miles), population, race, median household annual income, state and city bike-friendly ranking, bikeshare availability, number of bikeshare stations, public transit (including bike racks' availability), percentage of household without vehicle, average number of vehicles per household, protected bike lane availability, average monthly temperature, average annual precipitation, and average annual snowfall for every potential city (Tables 1 and 2).

Table 1. Data for Candidate Cities (part 1)

No.	State	City	Urbanized land area 2010 (square miles)	Population	Nonwhite percentage (%)	Median household annual income	State bike friendly ranking (2015)	City Bike-Friendly Ranking	No. of bikeshare stations	Percentage of households with no vehicles/%	Vehicles per household
1		Washington DC	1322	649,111	59.8	$67,572	-	Silver	373	37.9	0.9
2	Washington	Seattle	1010	652,405	29.4	$70,172	1	Gold	66	34.91	1.4
3	Minnesota	Saint Paul	52	294,873	39.9	$49,469	2	Bronze	146	14	1.5
4	Minnesota	Minneapolis	1022	400,070	29.8	$50,563	2	Gold	65	18.1	1.3
5	Massachusetts	Boston	1873	645,966	47.1	$53,583	4	Silver	140	35.8	0.9
6	Utah	Salt Lake City	278	191,180	24.9	$50,827	5	Silver	25	12.8	1.5
7	Oregon	Portland	524	609,456	23.9	$55,571	6	Platinum	Will develop	15	1.5
8	Colorado	Boulder	32	101,500	12	$57,428	7	Platinum	39	9	1.6
9	Colorado	Fort Collins	109	152,061	10.37	$56,464	7	Platinum	Will develop	5.4	1.9
10	Colorado	Denver	668	649,495	30	$51,089	7	Silver	87	11.7	1.5
11	California	Sacramento	471	479,686	55	$48,034	8	Silver	Will develop	11.1	1.6
12	California	San Diego	732.4	1,355,896	57.1	$63,456	8	-	100	7.6	1.7
13	California	San Francisco	524	837,442	51.5	$77,485	8	Gold	84	30.4	1.1
14	Wisconsin	Madison	151	243,344	21.1	$49,546	9	Gold	36	13.1	1.4
15	Wisconsin	Milwaukee	545	599,164	63.1	$35,186	9	Bronze	35	19.2	1.3
16	Maryland	Baltimore	717	622,104	68.37	$42,266	10	Bronze	Will develop	30.6	1.1
17	New York	New York City	3450	8,406,000	67.3	$54,700	11	-	332	38.6	0.8
18	Pennsylvania	Pittsburgh	905	305,841	34	$42,004	12	Bronze	14	25.2	1.1
19	Pennsylvania	Philadelphia	1981	1,553,000	54.5	$36,836	12	Silver	60	33.1	1
20	Illinois	Chicago	2,443	2,719,000	68.3	$47,099	14	Silver	476	27.3	1.1
21	Michigan	Detroit	1337	688,701	91.1	$24,820	18	-	42	25.2	1.1
22	Arizona	Phoenix	1147	1,513,000	28.93	$46,601	19	Bronze	41	9.1	1.6

No.	State	City	Urbanized land area 2010 (square miles)	Population	Nonwhite percentage (%)	Median household annual income	State bike friendly ranking (2015)	City Bike-Friendly Ranking	No. of bikeshare stations	Percentage of households with no vehicles/%	Vehicles per household
23	Arizona	Tucson	353	526,116	52.8	$35,720	19	Gold	Will develop	12.7	1.5
24	Idaho	Boise	133	214,237	11.12	$47,847	21	Silver	27	6.4	1.7
25	Florida	Miami	1239	417,650	27.4	$31,070	24	Bronze	75	21.5	1.2
26	Georgia	Atlanta	2645	447,841	61.6	$46,485	25	-	Will develop	16.9	1.3
27	Rhode Island	Providence	545	177,994	45.47	$36,378	26	-		19.6	1.3
28	Texas	Houston	1660	2,196,000	50.7	$45,353	30	Bronze	29	10	1.5
29	Texas	Austin	523	885,400	34.64	$56,351	30	Silver	50	6.9	1.6
30	Texas	Fort Worth	1779.1	792,727	40.31	$52,430	30	-	43	6.5	1.7
31	Missouri	Kansas City	678	467,007	39.32	$45,551	34	Bronze	27	11.2	1.5
32	South Carolina	Spartanburg	190	37,647	52.89	$32,499	44	Bronze	5	-	-
33	Alabama	Birmingham	530	212,113	77.7	$31,152	50	-	40	15.1	1.4
34	Montana	Missoula	45.2	66,788	6.43	$44,232	46	Gold	Rent bike shop	7	1.7

Note: 1. All data were collected from September to December 2015;
2. "-" indicates that no information was available;
3. City area and population data are from the website links: https://www.census.gov/dataviz/visualizations/026/508.php, https://en.wikipedia.org/wiki/List_of_United_States_cities_by_population_density, and https://en.wikipedia.org/wiki/List_of_United_States_urban_areas;
4. Race percentage data are from Wikipedia;
5. Median household income data are from the website link: http://www.city-data.com/;
6. Bicycle friendly data are from the official website of the League of American Bicyclists;
7. Vehicle ownership data are from the website link: http://www.governing.com/gov-data/car-ownership-numbers-of-vehicles-by-city-map.html;
8. The population of Chicago in this table is 2,719,000, which is different from the population (2,869,555) calculated later. The reason is that we included some areas (e.g., Evanston in the north of Chicago) where has been covered by the Chicago bikeshare system (Divvy);
9. The population of Philadelphia is 1,553,000 in this table, which is slightly greater than 1,551,773 calculated by 2010 Census data later;
10. The size of some bikeshare systems increased during our research period. The number of the bikeshare stations in Chicago increased from 476 to 581. The bikeshare system (Indego) in Philadelphia had 105 bikeshare stations when the report was done in September 2017.

Table 2. Data for Candidate Cities (part 2)

No.	State	City	Public Transit		Protected bike path	Average monthly temperature (°F)				Average annual precipitation		Average annual snowfall (inch)
			Bus transit/Bike racks' available	Metro or railway/Bike racks' available		Jan.	April	July	Oct.	inch	days	
1	DC	Washington DC	Metrobus/Yes	Washington Metro/Yes	Yes	34.9	56.1	79.2	58.8	39.35	113	17.1
2	Washington	Seattle	King County/Yes	Seattle Center Monorail and link light rail/No	Yes	40.9	50.2	65.3	52.7	37.07	155	11.4
3	Minnesota	Saint Paul	Metro Transit/Yes	Metro/-	-	13.1	46.6	73.2	48.7	29.41	115	49.9
4	Minnesota	Minneapolis	Metro Transit/Yes	Metro/-	Yes	13.1	46.6	73.2	48.7	29.41	115	49.9
5	Massachusetts	Boston	MBTA Bus/Yes	MBTA/Yes (some available)	Yes	29.3	48.3	73.9	54.1	42.53	127	42.8
6	Utah	Salt Lake City	Utah Transit Authority/Yes	Trax light rail/-	Yes	29.2	50	77	52.5	16.5	91	58.7
7	Oregon	Portland	TriMet/Yes	Max light railway/Yes	Yes	39.9	51.2	68.1	54.3	37.07	153	6.5
8	Colorado	Boulder	RTD/Yes	No/-	Yes	34.6	49.5	72.5	51.8	20.66	89	89
9	Colorado	Fort Collins	Transfort/Yes	No/-	Yes	31.1	41.5	66.5	50.1	16.05	81	57
10	Colorado	Denver	RTD/Yes	Light Rail/Yes	Yes	29.2	47.6	73.4	51	15.81	89	60.3
11	California	Sacramento	Sacramento Regional Transit District (RT)/Yes	Light Rail/Yes	Yes	46.3	58.9	75.4	64.4	17.93	58	-
12	California	San Diego	San Diego Metropolitan Transit System/Yes	Trolley car/Yes	-	57.8	62.6	70.9	67.6	10.77	41	-
13	California	San Francisco	Golden Gate Transit/Yes	Light Rail and Bay Area Rapid Transit/Yes	Yes	49.4	56.2	62.8	61	20.11	63	-
14	Wisconsin	Madison	Madison Metro/Yes	No/-	Yes (only one)	17.3	45.9	71.6	49.3	32.95	120	43.8

No.	State	City	Public Transit		Protected bike path	Average monthly temperature (°F)				Average annual precipitation		Average annual snowfall (inch)
			Bus transit/Bike racks' available	Metro or railway/Bike racks' available		Jan.	April	July	Oct.	inch	days	
15	Wisconsin	Milwaukee	Milwaukee County Transit System/Yes	No/-	Yes (only one)	20.7	45.2	72	51.4	34.81	125	47
16	Maryland	Baltimore	Maryland Transit/Yes	Light Rail and Baltimore Metro Subway/-	Planning	32.3	53.2	76.5	55.4	41.94	115	21.5
17	New York	New York City	MTA Subway/Yes	Train or light rail/Yes (only off rush hour)	-	23.6		82		46.42	122	26.7
18	Pennsylvania	Pittsburgh	PAT Transit/Yes	Light Rail/-	Yes	27.5	49.9	72.6	52.5	37.85	152	43.6
19	Pennsylvania	Philadelphia	SEPTA/Yes	Regional Rail and PATCO Speedline/Yes	Yes	32.3	53.1	77.6	57.2	42.05	117	20.8
20	Illinois	Chicago	CTA/Yes	light Rail / Yes	Yes	22	47.8	73.3	52.1	36.27	125	38
21	Michigan	Detroit	Detroit Department of Transportation/ Yes	Ann Arbor-Detroit Regional Rail/-	Yes	24.5	48.1	73.5	51.9	32.89	135	41.3
22	Arizona	Phoenix	Valley Metro/Yes	Light Rail/Yes	Yes	54.2	70.2	92.8	74.6	8.29	36	-
23	Arizona	Tucson	Sun Tran/Yes	StreetCar/Yes	Yes	51.7	66	86.5	70.5	12.17	53	1.2
24	Idaho	Boise	Valley Regional Transit/Yes	No/-	Planning	30.2	50.6	74.7	52.8	12.19	89	20.6
25	Florida	Miami	Metrobus/Yes	Metrorail/Yes		68.1	75.7	83.7	78.8	58.53	131	-
26	Georgia	Atlanta	MARTA Bus/Yes	MARTA Train/Yes	Yes	42.7	61.6	80	62.8	50.2	115	2.1
27	Rhode Island	Providence	Rhode Island Public Transit Authority/Yes	No/-	-	28.7	48.6	73.3	53	46.45	124	36
28	Texas	Houston	METRO Bus/Yes	Metrorail/Yes	Yes	51.8	68.5	83.6	70.4	47.84	105	0.4

No.	State	City	Public Transit		Protected bike path	Average monthly temperature (°F)				Average annual precipitation		Average annual snowfall (inch)
			Bus transit/Bike racks' available	Metro or railway/Bike racks' available		Jan.	April	July	Oct.	inch	days	
29	Texas	Austin	Capital Metropolitan Transportation/Yes	Metrorail/Yes	Yes	50.2	68.3	84.2	70.6	33.65	85	0.9
30	Texas	Fort Worth	The T/Yes	DART Rail/Yes	-	44.1	65	85	67.2	34.73	79	2.6
31	Missouri	Kansas City	KCATA/ Yes	No/-	Planning	26.9	54.4	78.5	56.8	37.98	104	19.9
32	South Carolina	Spartanburg	SPARTA/Yes	No/-	-	42	60.4	79.2	61.1	48.45	101	1.6
33	Alabama	Birmingham	MAX/ Yes	No/-	Yes	42.6	61.3	80.2	62.9	53.99	117	1.5
34	Montana	Missoula	Mountain line/Yes	No/-	Yes	20.2	44.1	67.8	44.8	14	102	36.9

Note: 1. All data were collected from September to December 2015;
2. "-" indicates that no information was available;
3. Protected bike path data are from the website link: https://docs.google.com/spreadsheets/d/11H0gArHxo6kMop1I18yMcq7ArbNrwaGBLmIXgqI1Gjk/edit;
4. Climate and weather date are from the website links: http://www.usclimatedata.com/, https://www.infoplease.com/science-health/weather/climate-100-selected-us-cities, and https://batchgeo.com/map/us-cities-rainy-days-per-year;
5. Public transit data are from the website links: https://en.wikipedia.org/wiki/List_of_bus_transit_systems_in_the_United_States, https://en.wikipedia.org/wiki/List_of_United_States_rapid_transit_systems_by_ridership, https://en.wikipedia.org/wiki/List_of_United_States_light_rail_systems_by_ridership.

We then recruited 16 experts from five different fields (bikeshare academics, bikeshare companies, metropolitan planning organizations (MPO), bike advocates, and local government) and asked them to rank the 34 cities across the available data in terms of usefulness for our study. We have provided the ranking methodology details and results in the supplemental material. From our candidate cities, we elected to use Chicago and Philadelphia for our study.

The Chicago Department of Transportation (CDOT) launched the current 581 stations, Divvy bikeshare program in 2013, contracting with Motivate to purchase, install, and operate the system. The program acquired start-up funding from federal projects aimed at promoting economic recovery, reducing traffic congestion and improve air quality; funds were also provided from the City's Tax Increment Financing program [29]. Chicago also recently introduced the "Divvy for Everyone (D4E)" program, which provides affordable membership fee to qualifying residents in July of 2015 [30].

Indego, which is owned by the City of Philadelphia, was planned and managed by the Office of Transportation & Infrastructure Systems. Bicycle Transit Systems operates and maintains the bikes and the technology platform, which is provided by B-Cycle [31]. The system started in 2015 and currently has 105 bikeshare stations. Philadelphia made a concerted effort to learn from other bikeshare systems before launching their own [32]. One of the critical aspects considered prior to launch was the social equity issue. Andrew Stober from the Mayor's Office of Transportation and Utilities in Philadelphia pointed out that areas outside of the business core should be an important part of a new bikeshare system [32, 33]. Partially as a result, Indego implemented a reduced membership fee plan for low-income residents, including a cash payment option for its users, at the same time when the program started [34-37].

Demographic Information

We assembled demographic information (population, race, median household annual income, and household vehicle number data), cycling infrastructure maps, and locations of essential services (transit stations, grocery stores, hospitals, and schools) for both Chicago and Philadelphia. We used the Census 2010 for demographic data and OpenStreetMap[2] and local government data portal[3] for the cycling path information. We mapped essential services using the Google Map API, which can return a large inventory of places (transit stations, grocery stores, hospitals, and schools) within a specified search radius based on the user's location.

[2] This database contains all the road information for a selected area (https://mapzen.com/data/metro-extracts/). In the database, there are many tags for a single path. For example, a path may be tagged with "pedestrian way" and "bicycle lane" at the same time. In our analysis, we classified those paths into "Designated Pedestrian Bike Share Path", "Designated Pedestrian Path", "Designated Bike Path", "Vehicle Road with Pedestrian and Bike Path", "Vehicle Road with Pedestrian Path", "Vehicle Road with Bike Path", "Pedestrian Path", "Bicycle Path", "Pedestrian and Bicycle Path'.

[3] Chicago government data portal (https://data.cityofchicago.org/Transportation/Bike-Routes/3w5d-sru8) and Philadelphia open data resource (https://www.opendataphilly.org/dataset/bike-network).

We collected population and race at the census block level. For the purposes of our analysis, we classified Black or African American, American Indian, Alaska Native, and Asian as minorities. We then calculated the percentages of people of color for every block group in Chicago and Philadelphia. The median household annual income and household vehicle number data are also at the census block group level. We assume that the ratio of household income and household vehicle ownership levels are the approximately same for every block within a block group.

Figures 1 through 10 present demographic information, bicycle infrastructure, and essential services in Chicago and Philadelphia. For both Chicago and Philadelphia, the block group with a median household annual income of less than $25,000 are largely coincident with block groups having people of color greater than 50% of their whole population. Households also tend to have fewer vehicles as we move toward the city central areas and finally, the densities of bicycle paths within block groups tend to be higher in central areas compared to suburban areas.

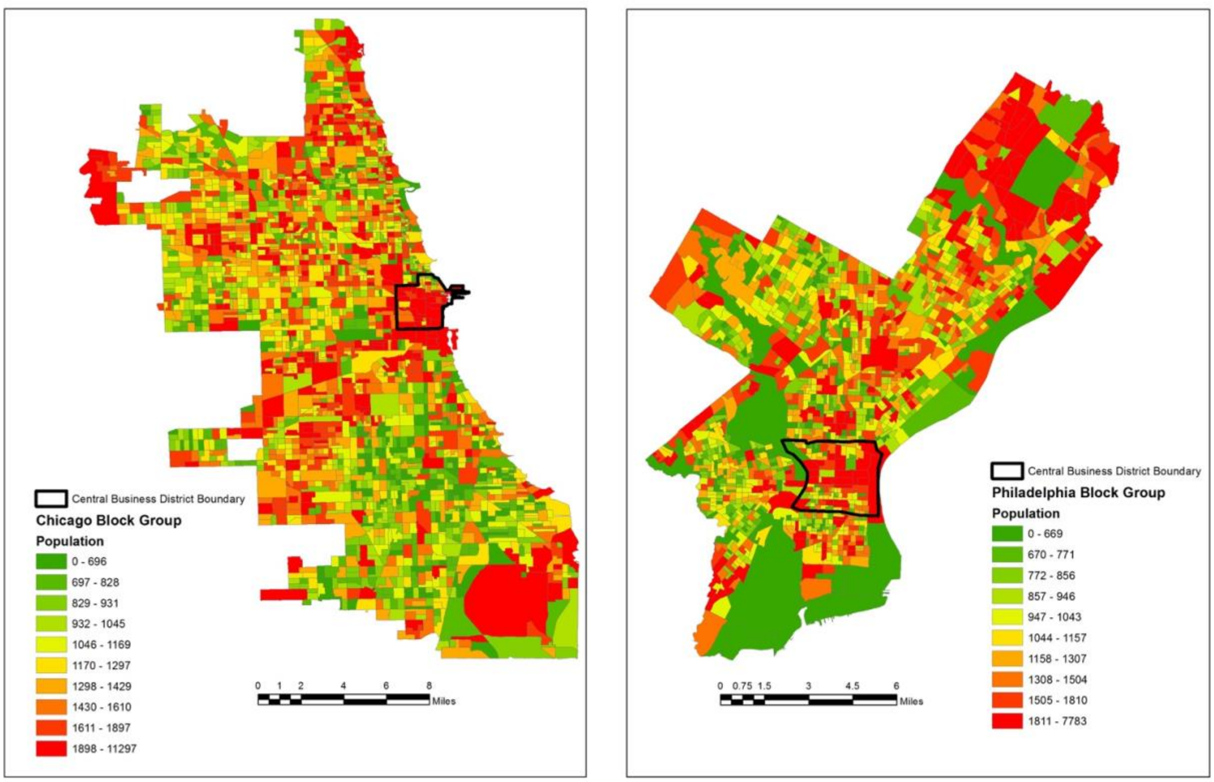


Figure 1. Population for Block Groups

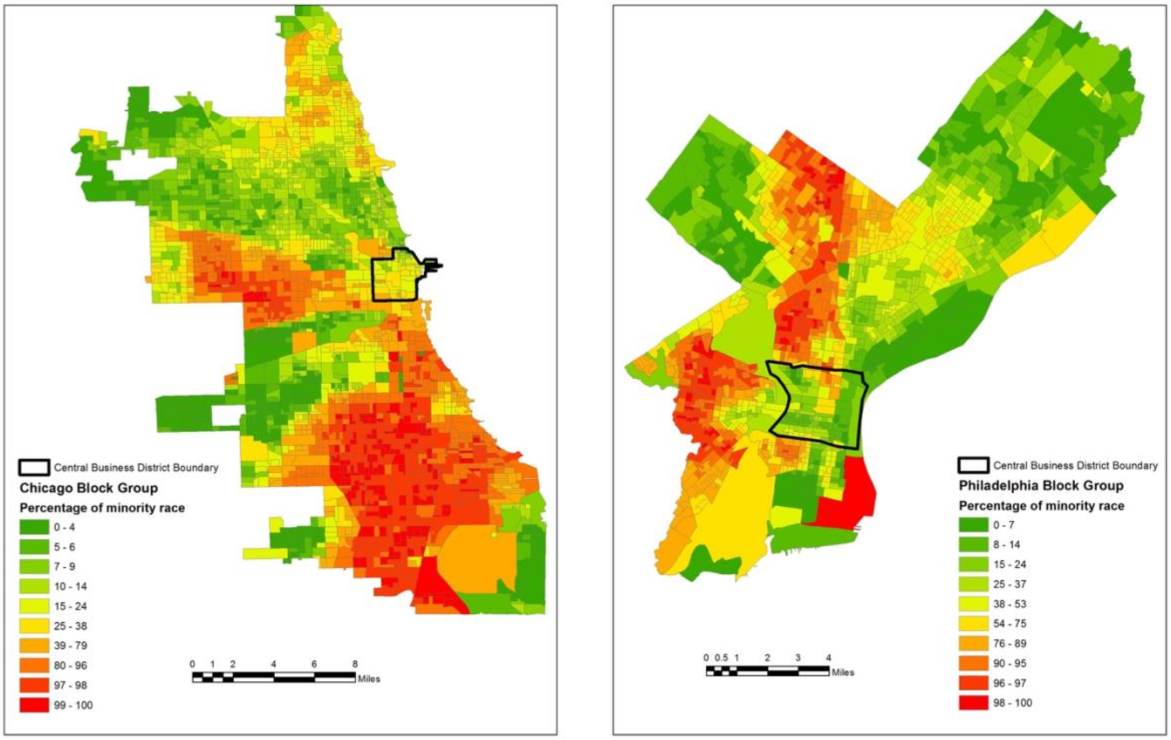


Figure 2. Percentage of Minority (People of Color) Population

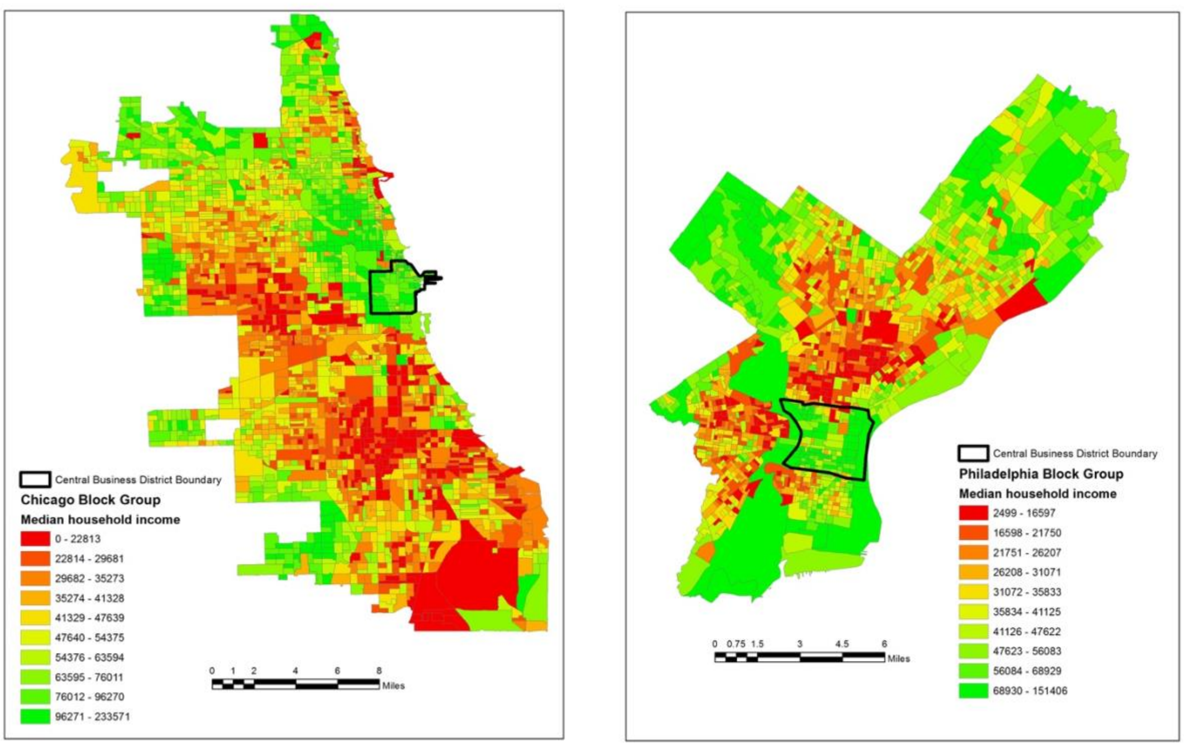


Figure 3. Median Household Income

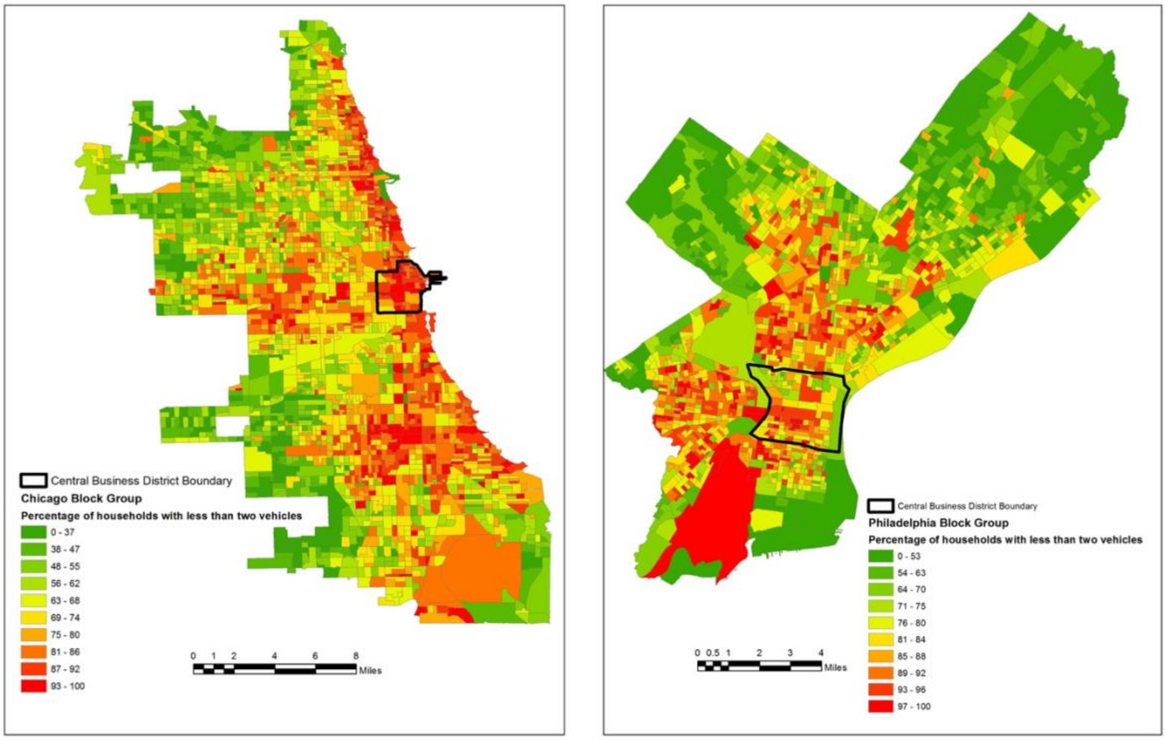


Figure 4. Percentage of Households with less than Two Vehicles

Figure 5. Bike routes

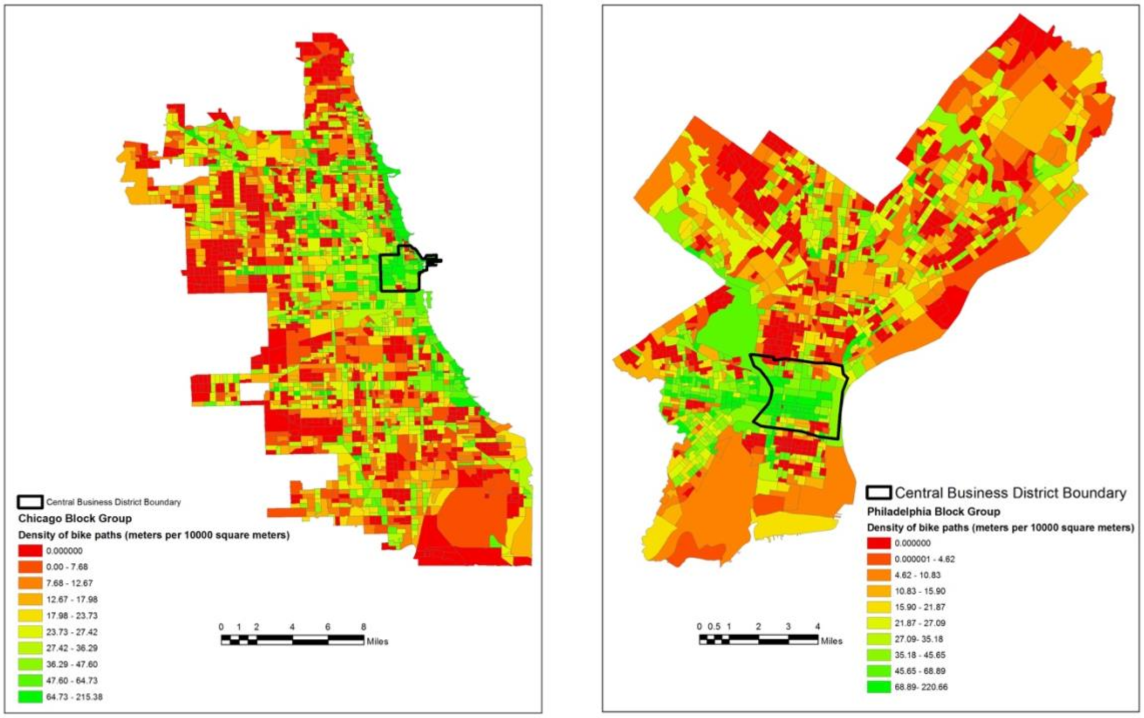


Figure 6. Density of bike paths

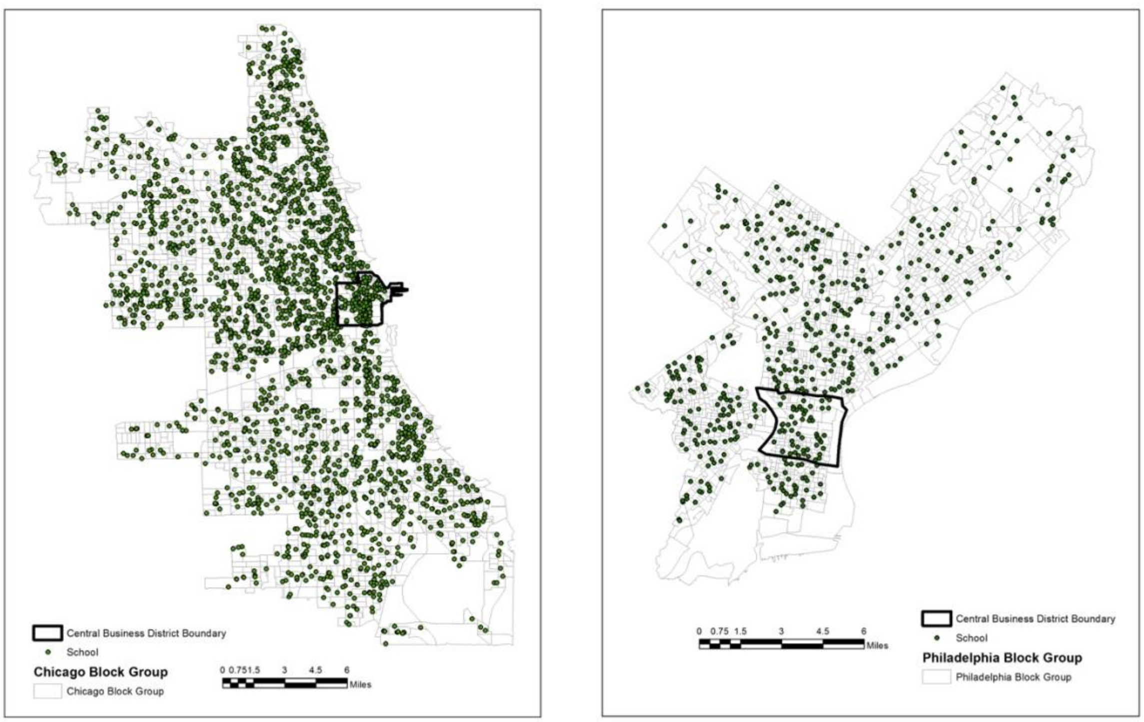


Figure 7. School locations

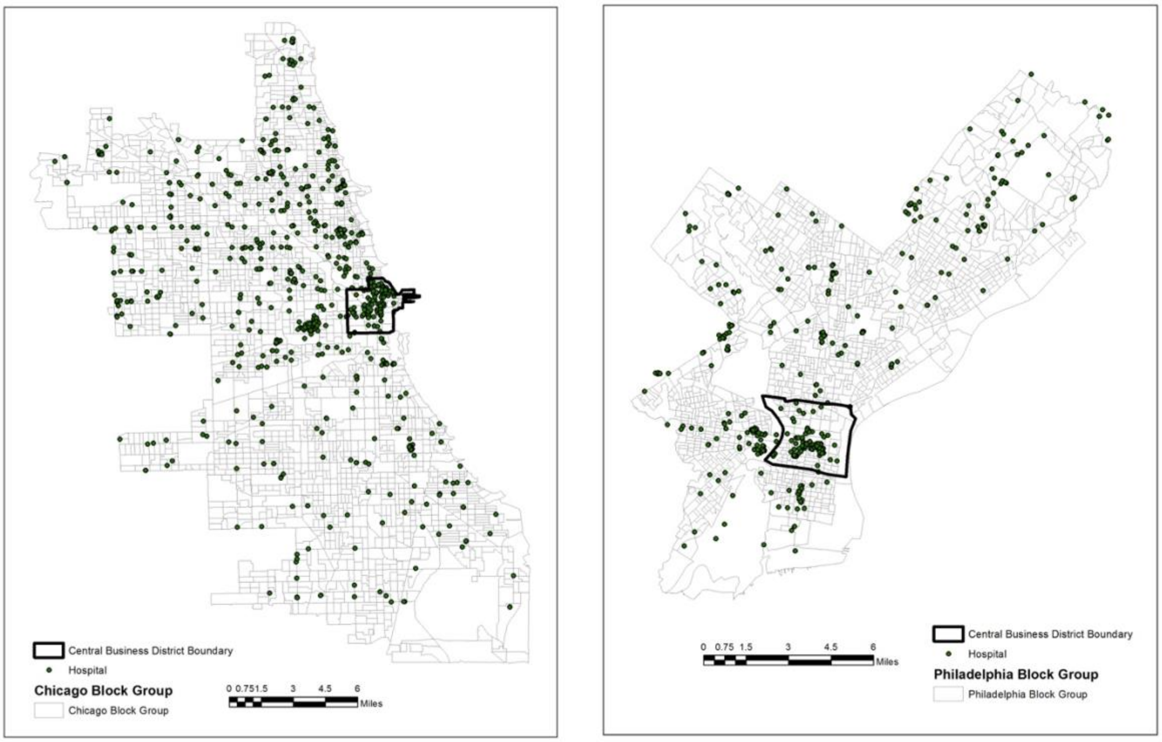


Figure 8. Hospital locations

Figure 9. Grocery store locations

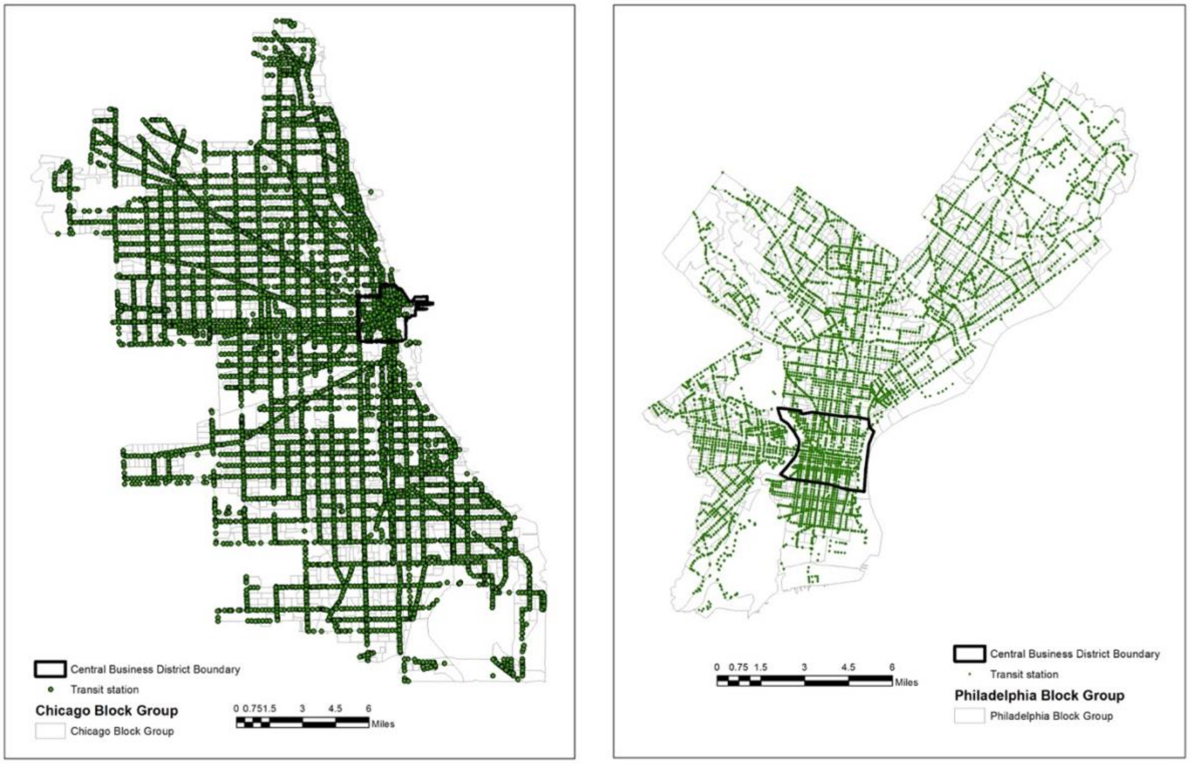


Figure 10. Transit station locations

Underserved Communities

We selected three criteria to use to designate underserved communities: median household income, percentage of people of color, and percentage of households owning zero or one vehicle. We distinguished potentially underserved areas by identifying those block groups with a median household income below $25,000, which uses the federal poverty definition for a household with four people ($24,300) [38]. We then set thresholds of low, moderate and high using the variables of the percentage of people of color and the percentage of households owning zero or one vehicle. The threshold levels for these two variables were established using the same approach as the North Central Texas Council of Governments (NCTCOG)'s applied in their "Bicycle Need Index" (the mean of data is used instead of the median of data in income) [39] (Table 3). We used the mean ±0.5 standard deviations to set each threshold level. So, for example, underserved areas would have a census block group with a median household annual income below $25,000, the percentage of people of color over 60.9% for Chicago and 70.9% for Philadelphia, and a percentage of households owning or renting 0-1 vehicle over 77.9% and 84.9% for Chicago and Philadelphia, respectively (Table 4).

Table 3. Thresholds for Classifications under Two Criteria

Data	Level	Value
People of color/Vehicle ownership	High	Percentage > Mean + 0.5 Standard deviations
	Moderate	Mean - 0.5 Standard deviations <= Percentage <= Mean + 0.5 Standard deviations
	Low	Percentage < Mean - 0.5 Standard deviations

Table 4. Classification of levels of served population

Level of served population	Median household income	Percentage of people of color	Percentage of households owning or renting 0-1 vehicle
Underserved	< $ 25,000 per year	> 60.9% (C) / > 70.9% (P)	> 77.9% (C) / > 84.9% (P)
Moderately served		Everything else	
Adequately served	> $ 25,000 per year	< 22.4% (C) / < 35.7% (P)	< 59.1% (C) / < 67.8% (P)

Note: C denotes Chicago; P denotes Philadelphia.

Philadelphia has slightly more block groups (12.2%), and a larger population (10.2%) in the underserved category compared to Chicago (9.0% block group and 7.8% population) (Table 5). In both cities, the vast majority of the block groups were identified as moderately served areas: 68.6% for Chicago and 70.4% for Philadelphia. Recall that within the scale of our analysis, Chicago has almost twice the population as Philadelphia. The number of bikeshare stations in Chicago is approximately six times that of Philadelphia (581 vs 105 now). This likely reflects the system maturation; Indego (Philadelphia) is in the early stages of development, where Divvy (Chicago) has been running for almost four years.

Table 5. Number of block groups and population in different levels of served population

Level of served population	Chicago		Philadelphia	
	Block group	Population	Block group	Population
Underserved	207 (9.0%)	222887 (7.8%)	163 (12.2%)	158103 (10.2%)
Moderately served	1570 (68.6%)	1988856 (69.3%)	941 (70.4%)	1100891 (70.9%)
Adequately served	512 (22.4%)	657812 (22.9%)	232 (17.4%)	292779 (18.9%)
Total	2289	2869555	1336	1551773

Based on the criteria established in Table 4, there is no block group identified as underserved within the central business district (CBD) of Chicago. There are two block groups within the Philadelphia CBD classified as low-income, people of color, and limited accessibility areas.

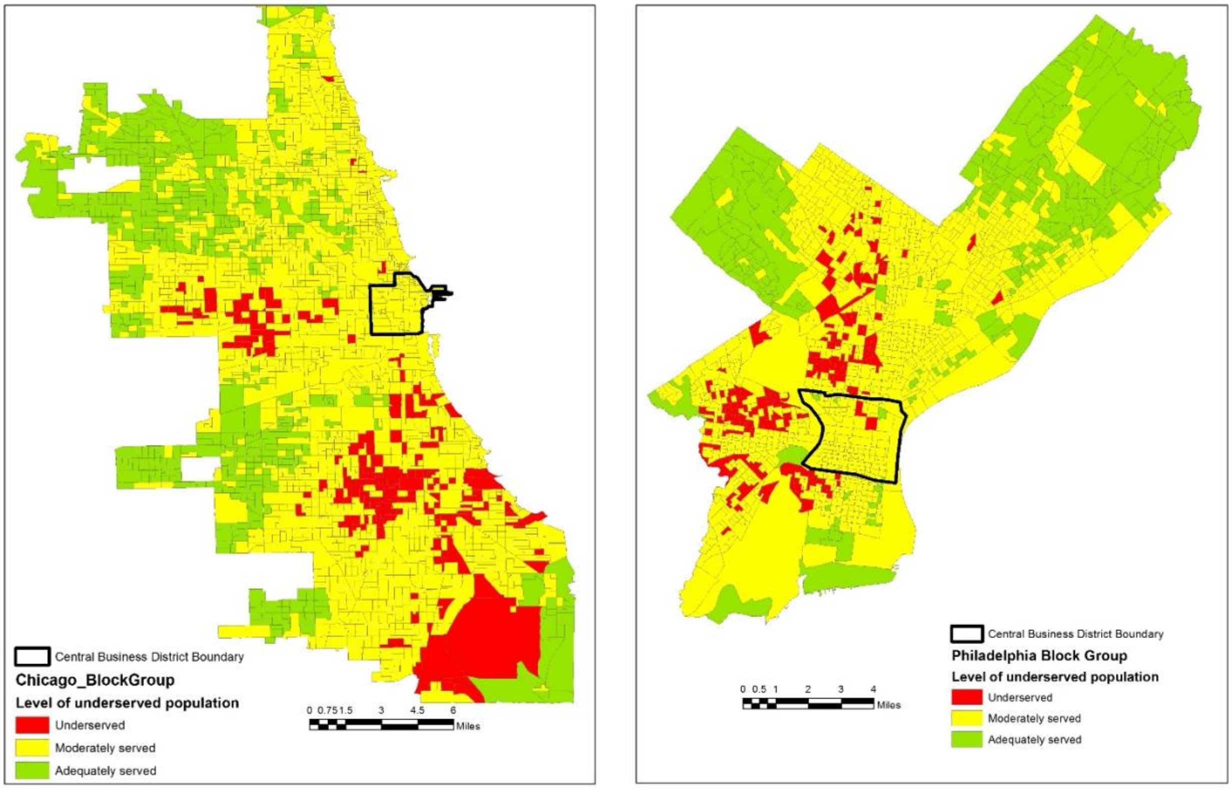


Figure 11. Distribution of block groups in different levels of served population in Chicago and Philadelphia

Bicycle Infrastructure

We calculated the total length of bicycle paths (including designated bicycle routes, bicycle pedestrian shared paths, and on-street paths) falling within each block group. Bike path density was then calculated for every block group as the total bike path divided by block group areas. The quantiles of bicycle path densities across all block groups are shown in Table 6. For Chicago and Philadelphia, the average bicycle path density across all block groups is between the 50% and 75% quantiles. From the maximum and the standard deviation in Table 6, we can conclude that bike lanes are spatially distributed more evenly among block groups in Chicago compared with Philadelphia. Philadelphia has more block groups with low bike path density, and the maximum bike path density in Philadelphia is greater than that of Chicago.

We followed the same process used to identify underserved communities to also divide block groups into different levels of bicycle infrastructure. The thresholds for analysis are shown in Table 6. Philadelphia has fewer block groups (22.7% in Chicago vs 19.2% in Philadelphia) and less population with access (23.6% in Chicago vs 18.7% in Philadelphia) identified as having a high level of bicycle infrastructure (Table 7). From the ArcGIS map (Figure 12), the areas with highest bicycle density tend to be almost exclusively in the CBD areas. Rural areas are more likely to have fewer bicycle paths (Figure 12).

Table 6. Statistics of bicycle path length density within block groups

Quantile		Chicago	Philadelphia
25%		0[1]	0
50%		15	12
75%		33	32
Maximum		215	220
Mean		22.3	22.8
Standard deviation		28.0	32.1
	High	> 36.3	> 38.8
Threshold	Moderate	8.3 <= and <= 36.3	6.7 <= and <= 38.8
	Low	8.3 <	6.7 <

Note: 1. The unit is meter per 10000 square meters;

Table 7. Number of block groups and population in different levels of bicycle infrastructure

Level of bicycle infrastructure	Chicago		Philadelphia	
	Block group	Population	Block group	Population
High	520 (22.7%)	676942 (23.6%)	256 (19.2%)	290386 (18.7%)
Moderate	852 (37.3%)	1101726 (38.4%)	525 (39.3%)	636828 (41.1%)
Low	917 (40.0%)	1090887 (38.0%)	555 (41.5%)	624559 (40.2%)
Total	2289	2869555	1336	1551773

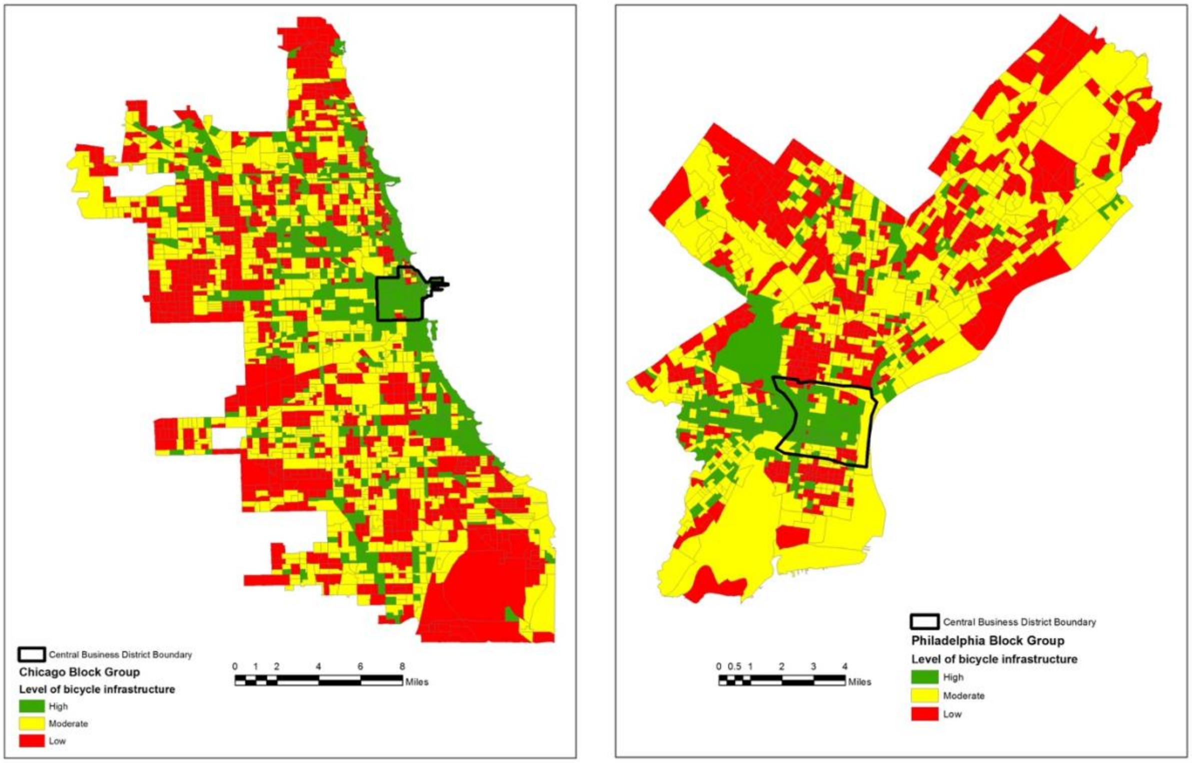


Figure 12. Level of bicycle path density within block groups

The relationship between the level of served population and the availability of bicycle infrastructure (as expressed by the density of biking facilities) is shown in Table 8 and Table 9. Compared with Chicago, underserved areas in Philadelphia have a larger proportion of block groups with a high level of bicycle infrastructure (3.1% in Philadelphia vs 2.0% in Chicago) (Table 8). Additionally, more block groups (3.1%) in underserved areas have access to a higher density of bike paths than block groups (1.2%) in adequately served communities in Philadelphia (Table 8). From the perspective of population, more residents (2.6% in underserved communities vs 1.2% in adequately served communities) are in higher levels of bike infrastructure areas in Philadelphia (Table 9). The situation is the opposite in Chicago.

Table 8. Distribution of block groups in cross-classification

Level of bicycle infrastructure	Level of served population					
	Underserved		Moderately served		Adequately served	
	Chicago	Philadelphia	Chicago	Philadelphia	Chicago	Philadelphia
High	46 (2.0%)	41 (3.1%)	411 (18.0%)	198 (14.8%)	63 (2.8%)	17 (1.2%)
Moderate	77 (3.4%)	53 (4.0%)	565 (24.6%)	363 (27.2%)	210 (9.2%)	109 (8.2%)
Low	84 (3.6%)	69 (5.1%)	594 (26.0%)	380 (28.4%)	239 (10.4%)	106 (8.0%)
Total	207 (9.0%)	163 (12.2%)	1570 (68.6%)	941 (70.4%)	512 (22.4%)	232 (17.4%)

Table 9. Distribution of population in cross-classification

Level of bicycle infrastructure	Level of served population					
	Underserved		Moderately served		Adequately served	
	Chicago	Philadelphia	Chicago	Philadelphia	Chicago	Philadelphia
High	51808 (1.8%)	40080 (2.6%)	550642 (19.2%)	231593 (14.9%)	74492 (2.6%)	18713 (1.2%)
Moderate	85374 (3.0%)	51054 (3.3%)	734697 (25.6%)	447928 (28.9%)	281655 (9.8%)	137846 (8.9%)
Low	85705 (3.0%)	66969 (4.3%)	703517 (24.5%)	421370 (27.1%)	301665 (10.5%)	136220 (8.8%)
Total	222887 (7.8%)	158103 (10.2%)	1988856 (69.3%)	1100891 (70.9%)	657812 (22.9%)	292779 (18.9%)

Quantifying Accessibility

In accessibility analysis, opportunities and travel time are two important components. In our research, opportunities refer to low-income jobs (with earning $3333/month or less), transit station (including bus and subway stations), grocery stores, hospitals, and schools. Low-income data were from Longitudinal Employer-Household Dynamics (LEHD) database. The location information of essential services (including transit stations, grocery stores, hospitals, and schools) was downloaded with Google API as mentioned earlier.

Travel time is associated with travel modes. For our analysis, we focus on measuring changes in accessibility with and without bikeshare to low-income jobs and essential services. Therefore, we measured the accessibility under two scenarios. First, we assume that the pedestrian system is used both alone and in conjunction with transit and then we measure accessibility assuming access to bikeshare infrastructure. We assume that bikeshare is available in residential areas, transit stations, and destinations for services in our analysis areas. We also assume that people can get access to bikeshare system regardless of location or time. In this way, we can identify where bikeshare systems can produce the greatest benefits (accessibility improvement) compared to the walk mode.

Travel time between block group pairs was calculated using the ArcGIS network analysis tool for the bike and pedestrian network, typical travel speeds, transit routes and stop locations. We assumed walk speed as three miles per hour and bike speed as ten miles per hour [40]. We measured accessibility in the standard way using Hansen's formula [41].

$$A_i = \sum_{j=1}^{N} O_j e^{-\beta t_{ij}}$$

where A_i is the accessibility of block group i, O_j is the opportunities available at block group j, N is the total number of blocks block group i can get access to within a specific time threshold,

β is an empirically-derived dispersion parameter, and t_{ij} is the travel time between block group i and block group j.

We calculated the accessibility scores for two different scenarios with different travel time budgets. The average accessibility changes were then calculated at different levels of served population groups (Figure 13). Changes in accessibility in Chicago are keeping increasing within ten minutes' travel time budget (except that underserved population groups have a small peak of accessibility change when travel time equals six). The figure suggests that accessibility improvement achieved by the bikeshare system slows down as the travel time budget increases. The same pattern is seen in Philadelphia. One difference is that moderately served communities have higher average accessibility improvement than underserved areas in Philadelphia. However, in both Chicago and Philadelphia, underserved areas can experience greater improvements in accessibility from bikeshare systems than wealthy and white dominated areas. The greatest average accessibility improvement for underserved areas is around five to six times in Chicago and Philadelphia. It is reasonable considering that the speed of bike (ten miles per hour) is three times as much as walk speed (three miles per hour). Within the same travel time budget, the accessible range through bikeshare is three times as much as by walk. Additionally, the areas can be reached through bikeshare is around nine times of that accessed by walk. In the same way, the accessibility is measured in a two-dimension space, which can be amplified by the extension in one dimension before and after bikeshare is available.

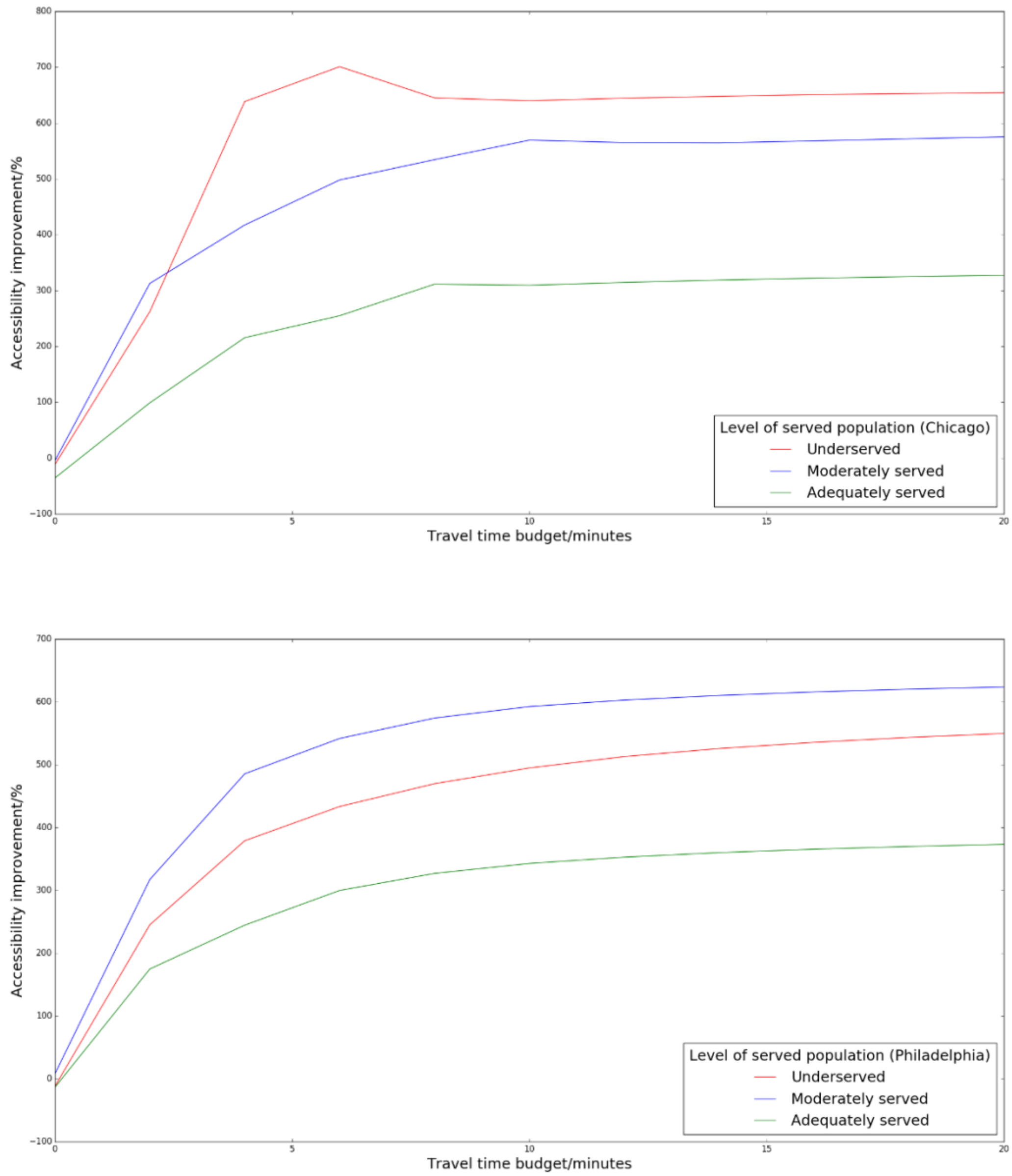


Figure 13. Average accessibility improvement for different groups with different travel time budgets

To measure accessibility improvement when bikeshare's effect is significant, we assume a travel time budget of ten minutes. To simulate travel behavior in the real world, we only considered opportunities within the distance of 10-minute walk or walk-to-transit for the walking scenario and within the distance of 10-minute cycling or cycling-to-transit for the bikeshare scenario. To set reasonable classification thresholds for levels of accessibility improvement, we used the interquartile range to identify outliers in accessibility improvement [42].

Results

We began our analysis by evaluating the current spatial distribution of bikeshare stations in Chicago and Philadelphia. We summed the availability of bikeshare stations in every block group and regressed the relation between bikeshare availability and demographic data. The regression results are listed in Table 10.

Table 10. Summary of logistic regression analysis for variables predicting bikeshare availability in a block group

Variable	Chicago		Philadelphia	
Population	3.979×10^{-4}	***[1]	5.49×10^{-4}	*
Income	1.366×10^{-5}	***	1.417×10^{-5}	*
Percentage of white	-6.344×10^{-4}		1.157×10^{-2}	*
Percentage of households with less than two vehicles	3.977×10^{-2}	***	7.411×10^{-2}	***
Bike path density	5.602×10^{-3}	***	1.577×10^{-4}	
Number of jobs	8.602×10^{-4}	***	6.142×10^{-4}	***
AIC	1911.8		513.17	

Note: 1. The dependent variable in the model above is the probability of bikeshare station availability (0: unavailable; 1: available) in a block group;

2. Significant codes: 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '~'.

As we can see that in both Chicago and Philadelphia, the availability of bikeshare stations is correlated to income levels. The percentage of white can be used to predict the availability of bikeshare stations in Philadelphia, which is not reflected in Chicago. We assumed that there is a correlation between income and percentage of white in both Chicago and Philadelphia. The regression results are shown in Figure 14.

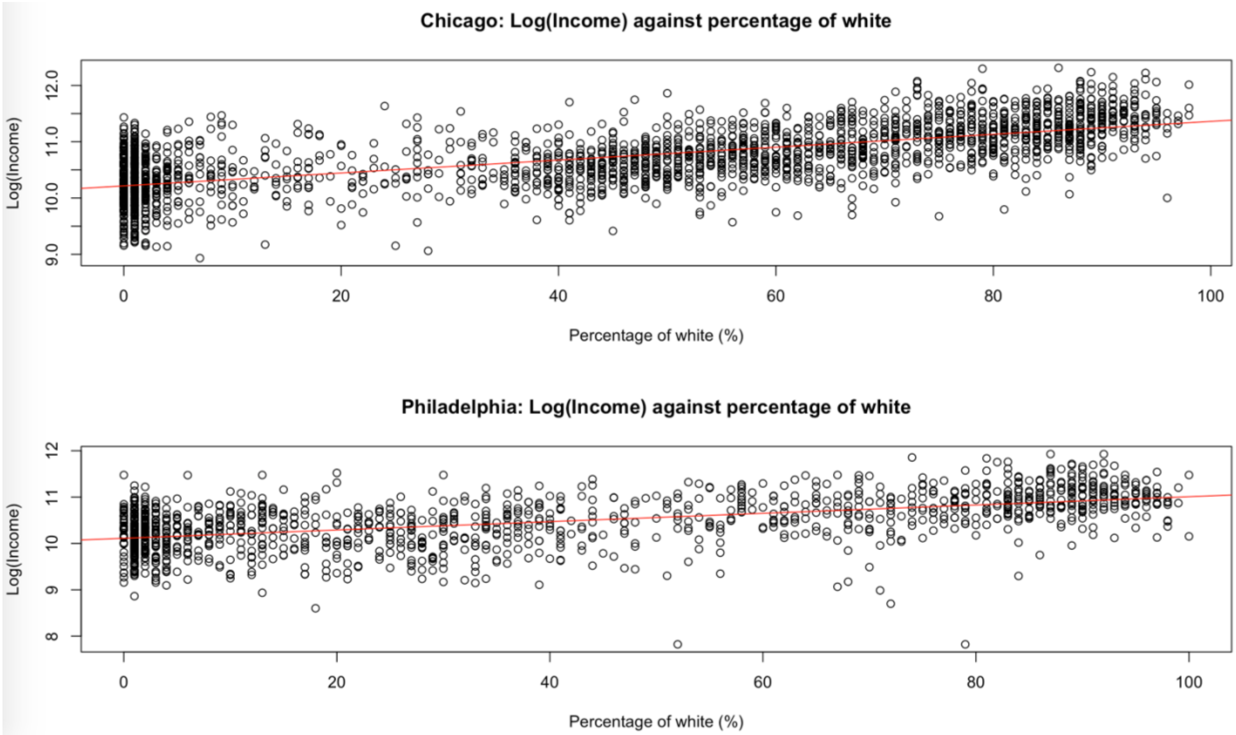
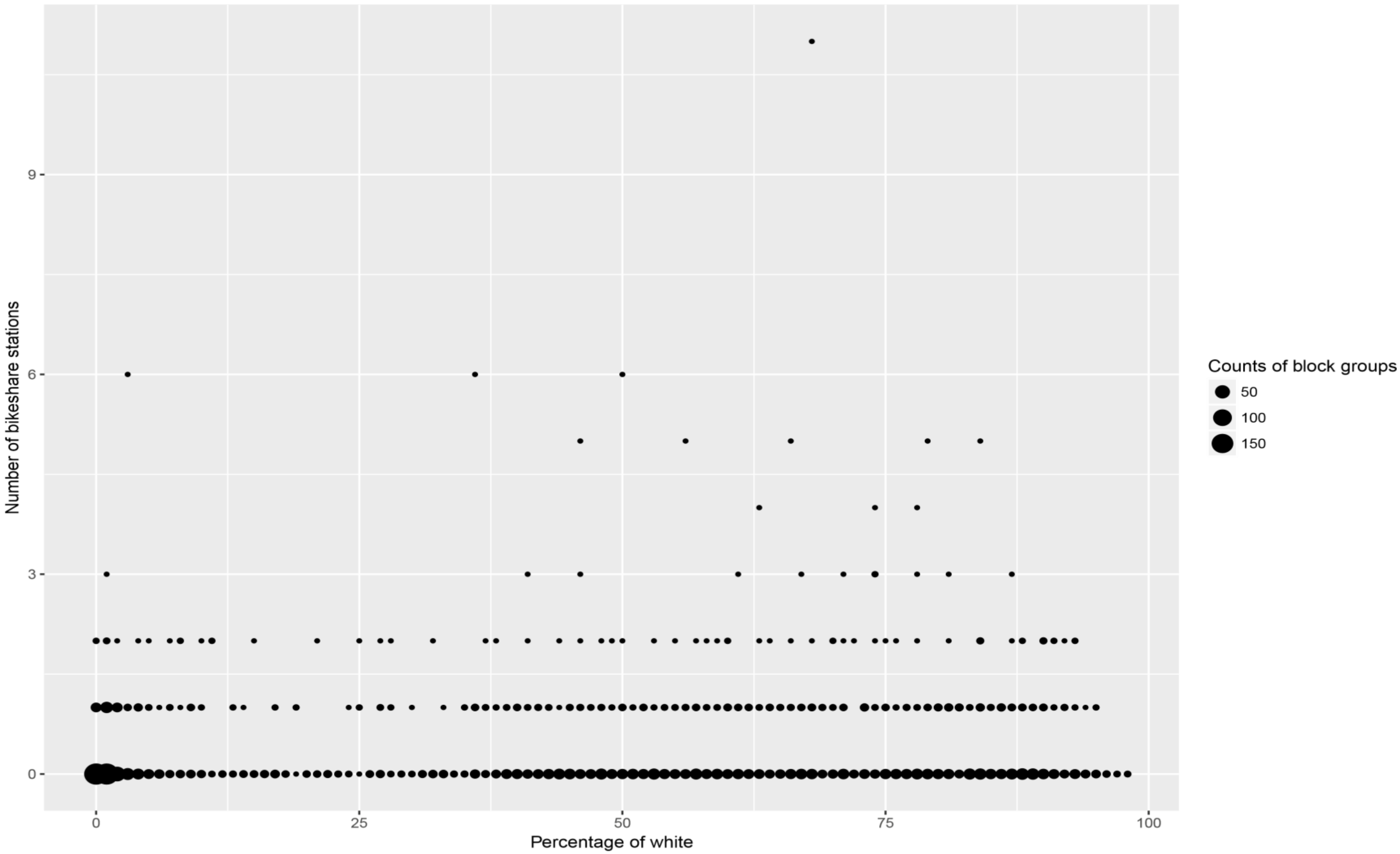


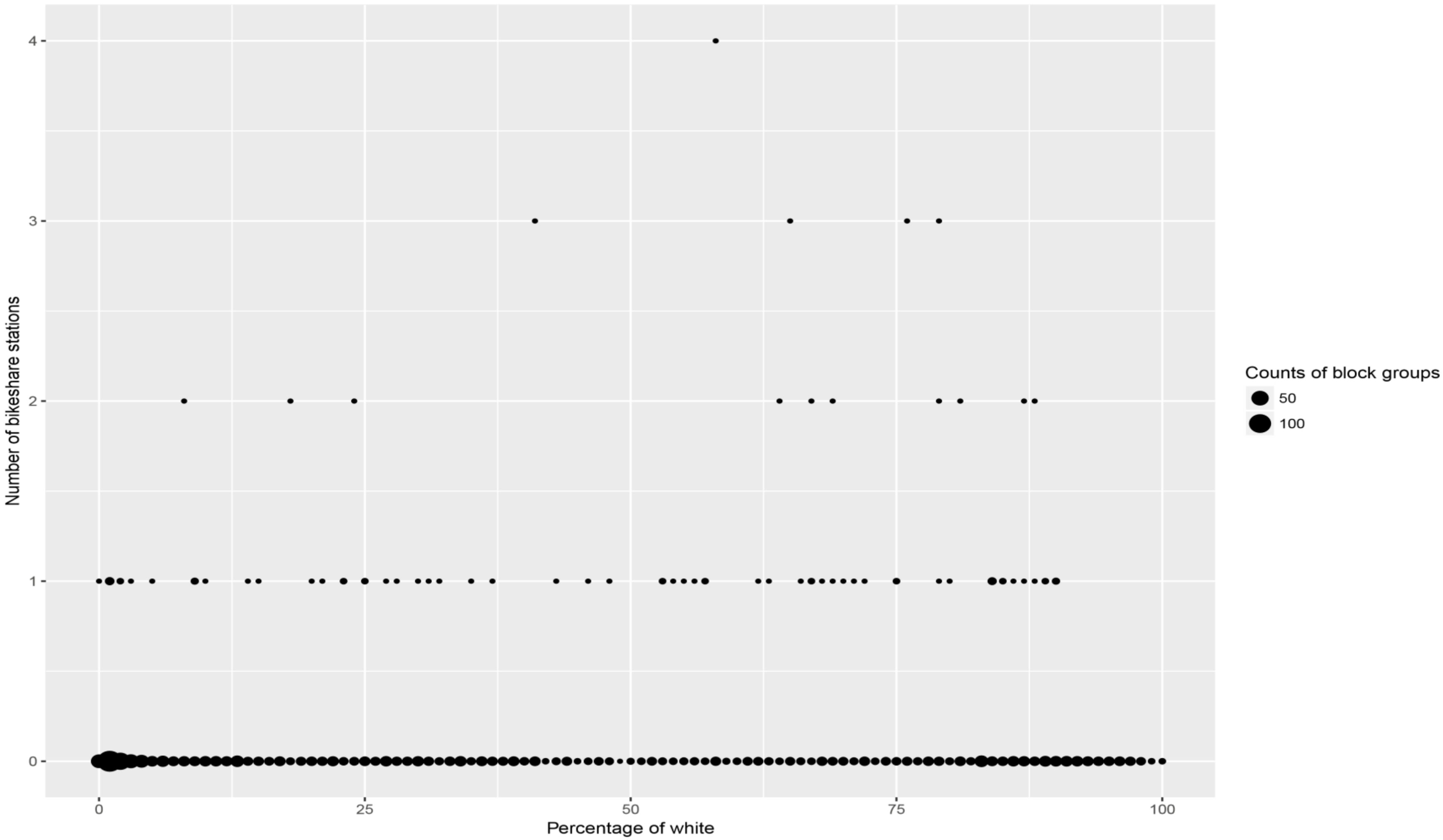
Figure 14. Log(income) against percentage of white people

Our modeling suggests that, in fact, bikeshare stations tend to be located in areas with a more affluent and white population. This is also consistent with Dill's survey investigation [11] and Aultman-Hall's demographic information analysis using bikeshare stations' buffer areas [43]. Additionally, the overall number of bikeshare stations in every block group tends to be higher in those block groups with a higher percentage of white population (Figure 15).



Number of bikeshare stations
0
3
6
9
0
25
50
75
100
Percentage of white
Counts of block groups
50
100
150

Chicago



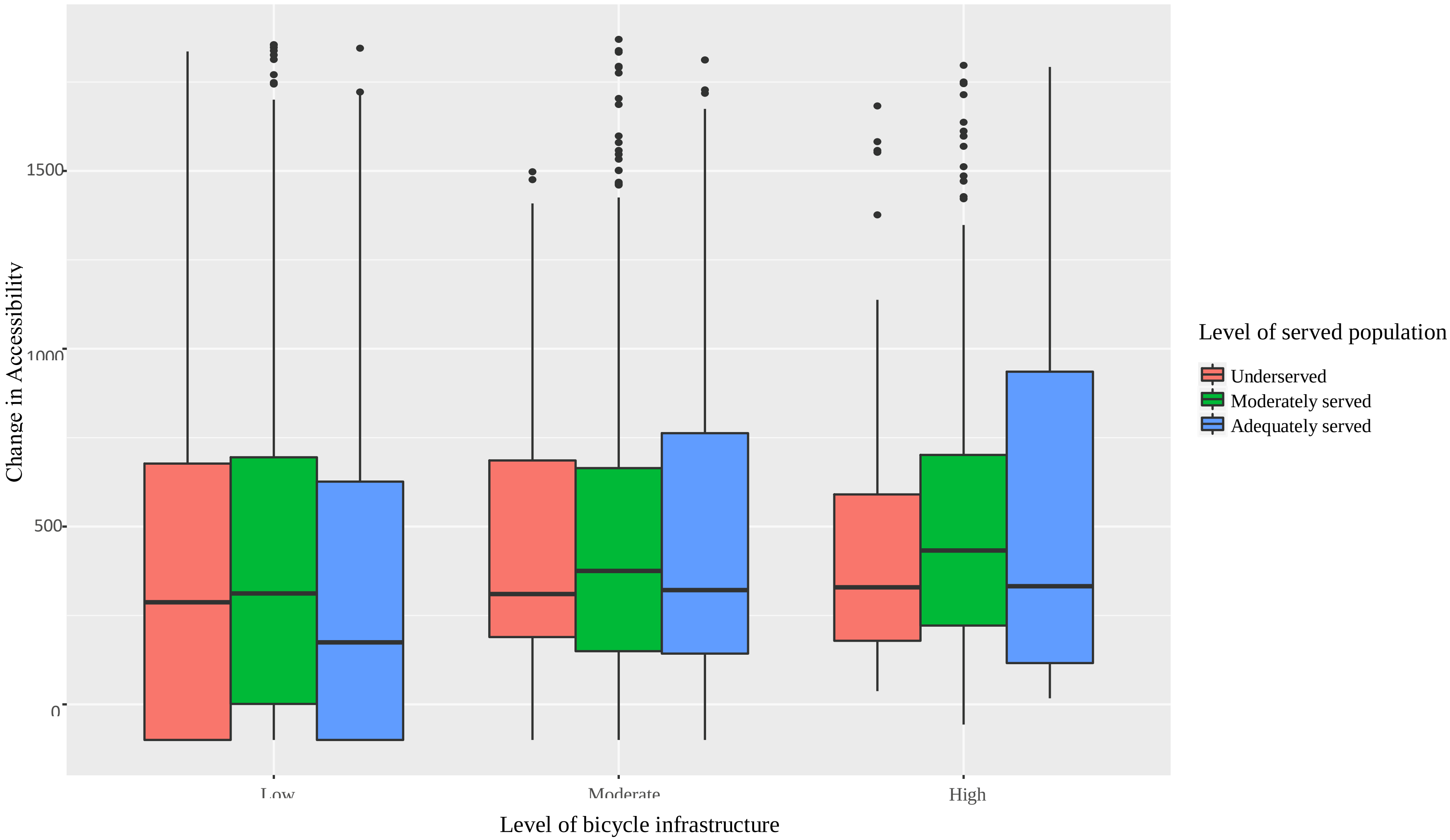
Philadelphia

Figure 15. Counts of Block Groups with Different Number of Bikeshare Stations

Our next question of interest was whether the presence of a bikeshare system with stations in proximity to underserved communities would in fact increase accessibility to essential services (jobs, transit stations, grocery stores, hospitals, and schools). We compared accessibility changes before and after the presence of a bikeshare system. To do this, we assumed that bikeshare was available to all communities and computed the change in accessibility over existing conditions.

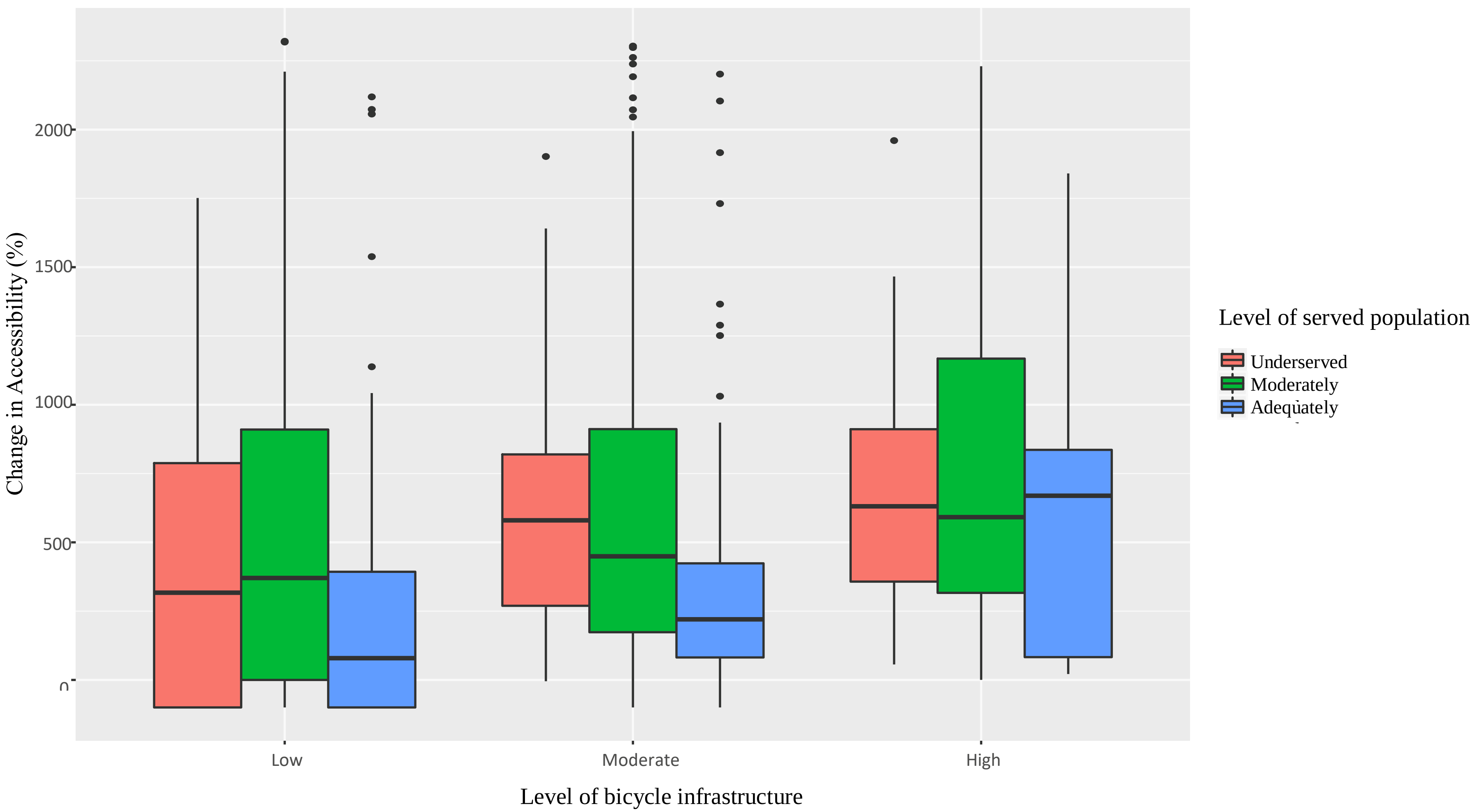
We found that the median changes in the percentage of accessibility in underserved and moderately served communities were higher than that for adequately served population communities when bike infrastructure levels are moderate and low in Philadelphia (Figure 16). That is, when the level of bike infrastructure is low, the differences in accessibility change within different levels of served populations are larger. This phenomenon only happens when the bike infrastructure level is low in Chicago (Figure 16). Areas with a high level of bike infrastructure have great overlaps with city central areas (Figure 12), where the transit system services are usually adequate. This may mitigate the accessibility improvement difference between underserved and adequately served areas because our accessibility analysis combined bike paths with transit network, or walk routes with transit network. Additionally, under the same level of served population, the median change of accessibility increases with the improvement of bike infrastructure (from low to high level). These findings suggest that the availability of a bikeshare system can produce significant accessibility improvements in underserved and moderately served populations, compared to adequately served communities when bike infrastructure is limited.

In Figure 17, we plotted the percent change in accessibility against bike path density. In both Chicago and Philadelphia, it shows the trend that accessibility improvement increases as the density of bike path increases. As we have found in bike infrastructure level classification, underserved communities in Chicago have limited bicycle paths. As a result, the red point (Chicago in Figure 17) disappears as bike path density increases. Additionally, underserved and moderately served communities are likely to gain more accessibility improvements than adequately served areas. The situation is more obvious in Philadelphia than Chicago. As we can see, many red (underserved) and green (moderately served) points are above blue (adequately served) points under different bike path densities in Philadelphia (Figure 17).



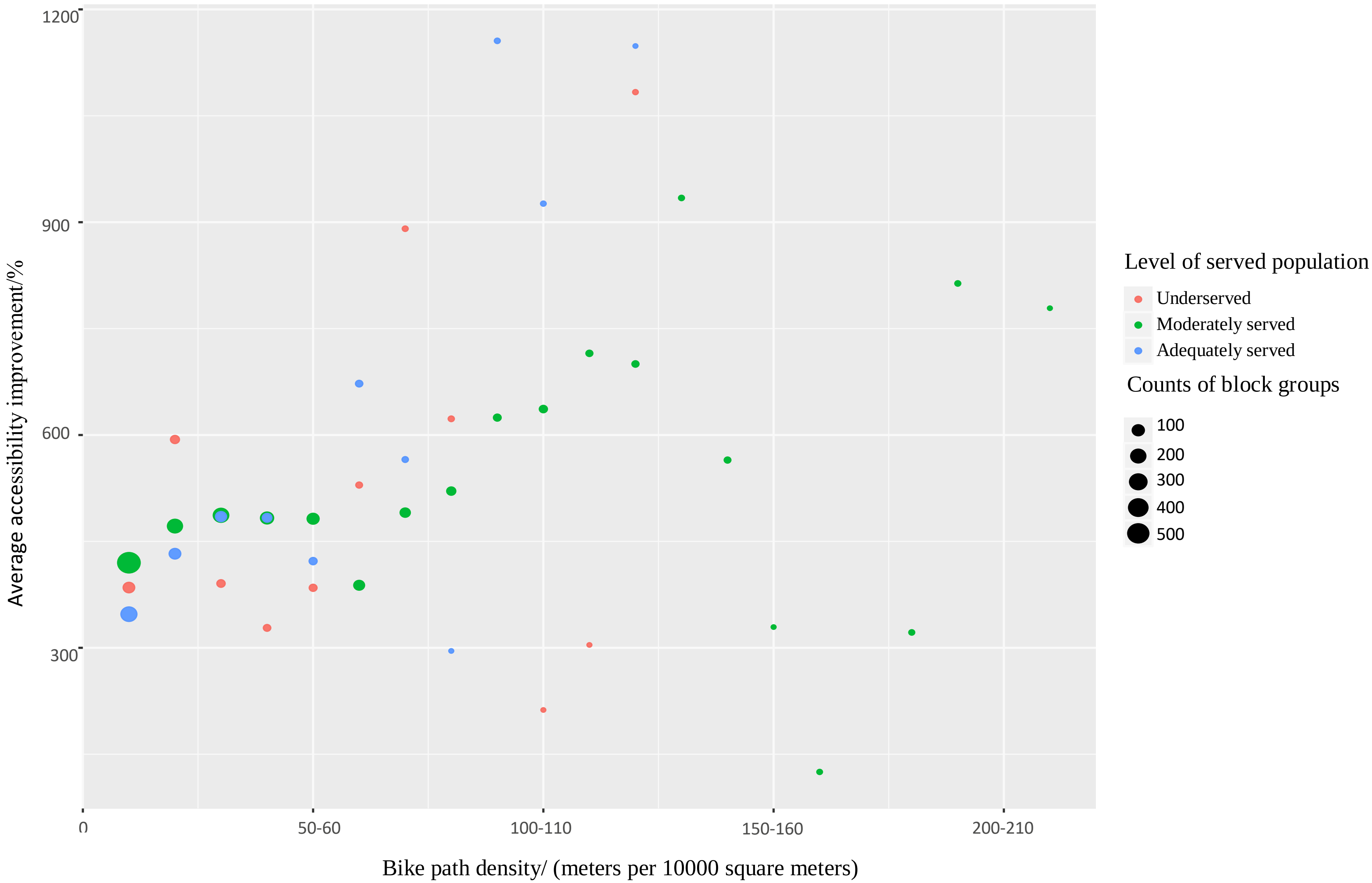
Change in Accessibility
1500
1000
500
0
Low
Moderate
High
Level of bicycle infrastructure
Level of served population
Underserved
Moderately served
Adequately served

Chicago



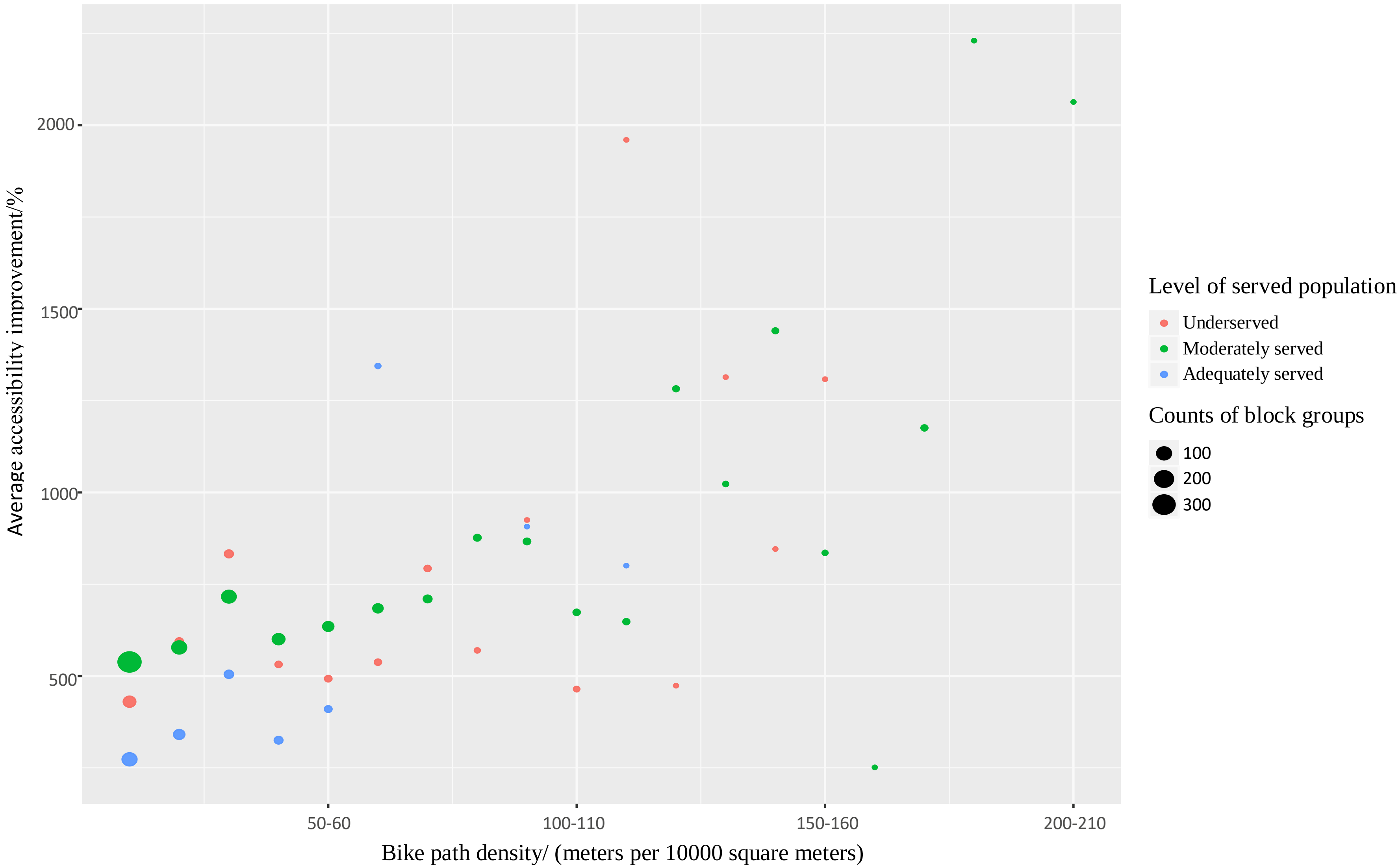
Philadelphia

Figure 16. Boxplot of Percentage of Accessibility Change for Different Level of Served Population and Bicycle infrastructure



1200
900
600
300
0
50-60
100-110
150-160
200-210
Average accessibility improvement/%
Bike path density/ (meters per 10000 square meters)
Level of served population
Underserved
Moderately served
Adequately served
Counts of block groups
100
200
300
400
500

Chicago



Philadelphia

Figure 17. Accessibility change against Bike Path Density

To understand the accessibility improvement for all block groups, the percentages of different results (improve/no change/reduce) of accessibility scores after a bikeshare system is available are summarized in Figure 18. The proportion of underserved block groups (blue bar in Figure 18) with increased accessibility is greater than that of adequately served block groups (grey bar in Figure 18) and vice versa when considering accessibility reduced.

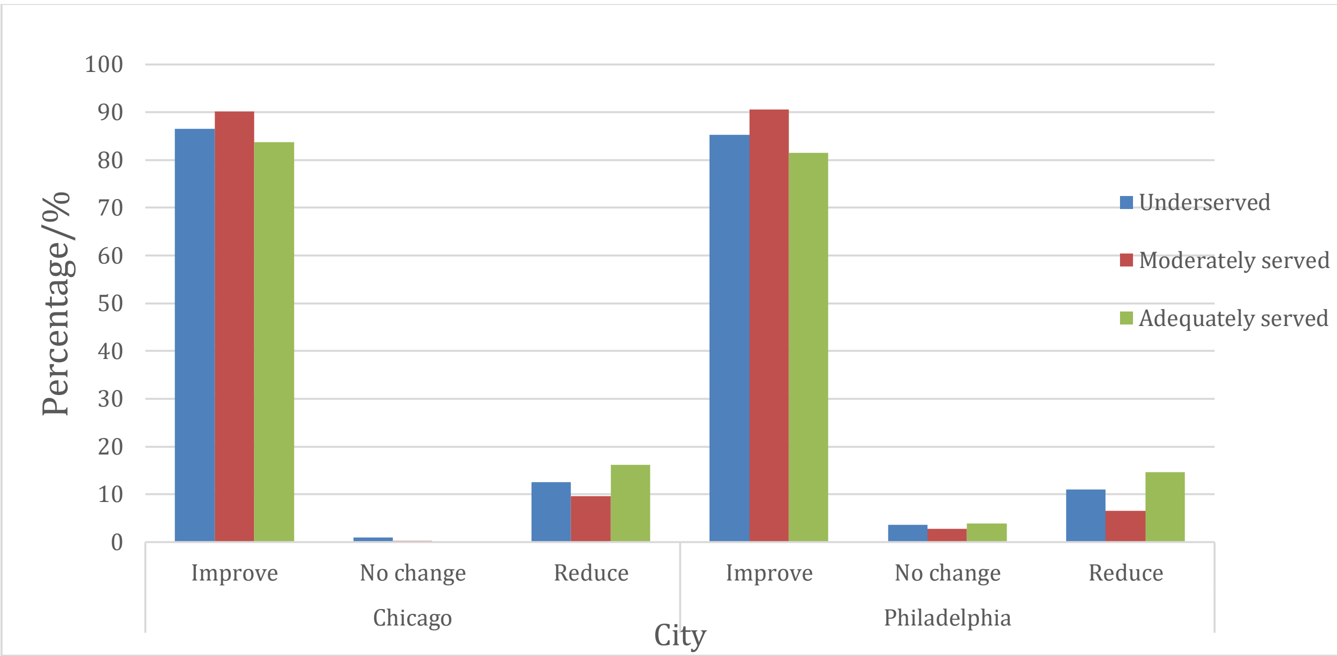


Figure 18. Percentage of block groups with different accessibility change (improve/no change/reduce)

We divided block groups into different levels of accessibility improvement (high, moderate, and low) with the thresholds shown in Table 11. The thresholds were set in the same manner with the classification of levels of bicycle infrastructure.

Table 11. Classification of levels of accessibility improvement

Data	Level	Chicago	Philadelphia
Accessibility improvement	High	> 673.42	> 847.48
	Moderate	225.80 <= and <= 673.42	272.14 <= and <= 847.48
	Low	< 225.80	< 272.14

In Chicago, the numbers of block groups are almost even in different levels of accessibility improvement (Table 12). However, Philadelphia has a larger portion of block groups with large accessibility improvement. This is largely due to the fact that Philadelphia is spatially smaller than Chicago.

Table 12. Number of block groups and population in different levels of accessibility improvement

Level of accessibility improvement	Chicago		Philadelphia	
	Block group	**Population**	**Block group**	**Population**
High	708 (30.9%)	832708 (29.0%)	577 (43.2%)	643488 (41.5%)
Moderate	776 (33.9%)	982564 (34.2%)	348 (26.0%)	380194 (24.5%)
Low	805 (35.2%)	1054283 (36.8%)	411 (30.8%)	528091 (34.0%)
Total	2289	2869555	1336	1551773

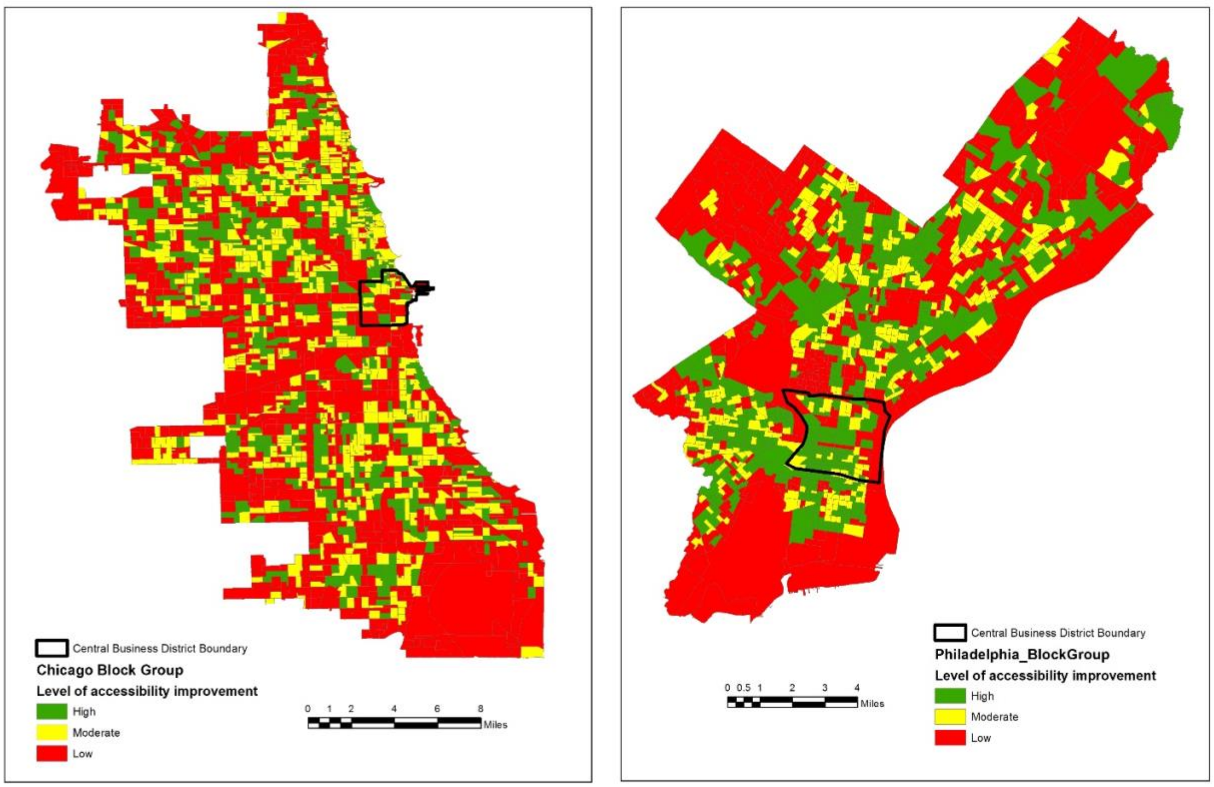


Figure 19. Distribution of Block Groups in Different Levels of Accessibility Improvement

Our results suggest that there is a strong potential for increased access to jobs and essential services with the expansion of bikeshare systems into underserved communities. By combining the locations of essential services and bike infrastructure information, we can also identify where bikeshare stations are likely to have the highest potential for increasing accessibility for underserved communities.

We classified each census block group into four different categories based on the quantiles of our variables: level of served population, level of bike infrastructure, and level of accessibility improvement. Four categories are defined based upon their potential to serve the needs of underserved populations and bicycle infrastructure levels as in Table 13. “Very high priority for bike share stations” refer to these locations with underserved populations, a high level of bike infrastructure quality, and a high potential for increased job and essential service access via bikeshare. “High priority for bike share stations” will cover areas that also have underserved populations, have a high or moderate level of bike infrastructure, and provide a high or moderate potential to increase accessibility. “Intermediate priority for bikeshare stations” are areas with moderately served populations, that have a high or moderate level of bike infrastructure or potential to increase accessibility. The last category is “high priority bikeshare and bike infrastructure combined need areas” that have underserved or moderately served populations, a low bike infrastructure quality, and a moderate to high potential for increased job and essential service access via bike share by underserved populations.

Table 13. Categories classification based on quantiles of three measures

Category	Level of served population			Level of bike infrastructure			Potential for increased Job and essential service access		
	Under-served	Moderately served	Adequately served	High	Moderate	Low	High	Moderate	Low
A	✓			✓			✓		
B	✓				✓		✓		
	✓			✓				✓	
	✓				✓			✓	
		✓		✓			✓		
C		✓			✓		✓		
		✓		✓				✓	
		✓			✓			✓	
D	✓					✓	✓		
	✓					✓		✓	
		✓				✓	✓		
		✓				✓		✓	

Note:
A: Very high priority for bikeshare stations
B: High priority for bikeshare stations
C: Intermediate priority for bikeshare stations
D: High priority bikeshare and bike infrastructure combined need areas

For Chicago, around 50% of all block groups are captured by the A through D categories; these block groups should be considered priority areas for the expansion of a bikeshare system. More than 60% of the block groups in Philadelphia are identified as priority areas for bikeshare stations. In both Chicago and Philadelphia, nearly a quarter of them (24.5%) are labeled with intermediate priority for bikeshare stations. Almost one-fifth of block groups (17.6% for Chicago and 21.3% for Philadelphia) are categorized to be high priority areas for bikeshare and bike infrastructure. It indicates that there are sufficient areas of demand to support bikeshare systems.

Table 14. Distribution of block groups in four categories in Chicago and Philadelphia

Category	Chicago	Philadelphia
A	15 (0.7%)	20 (1.5%)
B	208 (9.1%)	174 (13.0%)
C	561 (24.5%)	326 (24.5%)
D	403 (17.6%)	285 (21.3%)
Others	1102 (48.1%)	531 (39.7%)
Total number of block groups	2289	1336

Note:
A: Very high priority for bikeshare stations
B: High priority for bikeshare stations
C: Intermediate priority for bikeshare stations
D: High priority bikeshare and bike infrastructure combined need areas

We can also compare the current bikeshare stations to those we have classified (Table 15 and Figure 20). As we showed earlier in our modeling, it is clear that most of the current bikeshare stations are not located in underserved communities. In Chicago, the proportion of bikeshare stations in category D (High priority bikeshare and bike infrastructure combined need areas) is approximately twice as much as that in Philadelphia. It indicates that Chicago needs more bicycle infrastructure to support its bikeshare system.

In aspect of access for underserved areas to bikeshare systems, Philadelphia does better than Chicago if we compare the percentage of current bikeshare stations located in areas identified as high priority for bikeshare system (category A and category B). It shows that Indego owner has considered designing a bikeshare system with equitable access, which is mentioned in the introduction chapter. Even though Chicago has a larger-scale bikeshare system, Philadelphia can reach the same results or even better ones in terms of making bikeshare system equitable.

Table 15. Distribution of bikeshare stations in four different categories in Chicago and Philadelphia

Category	Chicago	Philadelphia
A	2 (0.3%)	1 (1.0%)
B	70 (12.0%)	33 (31.4%)
C	181 (31.2%)	24 (22.9%)
D	58 (10.0%)	6 (5.7%)
Others	270 (46.5%)	41 (39.0%)
Total number	581	105

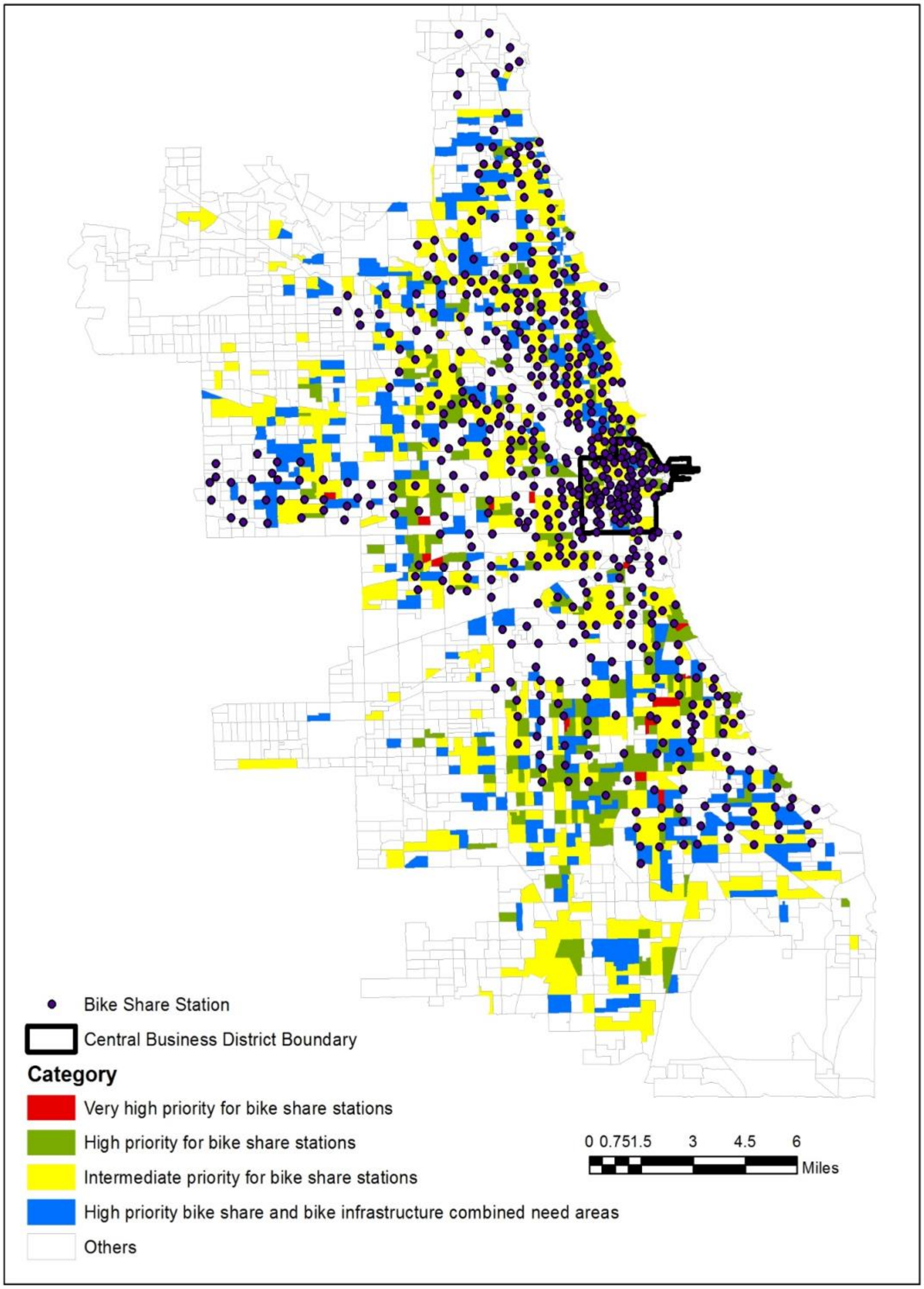
Note:

A: Very high priority for bikeshare stations

B: High priority for bikeshare stations

C: Intermediate priority for bikeshare stations

D: High priority bikeshare and bike infrastructure combined need areas


Bike Share Station
Central Business District Boundary
Category
Very high priority for bike share stations
High priority for bike share stations
Intermediate priority for bike share stations
High priority bike share and bike infrastructure combined need areas
Others
0 0.751.5 3 4.5 6
Miles

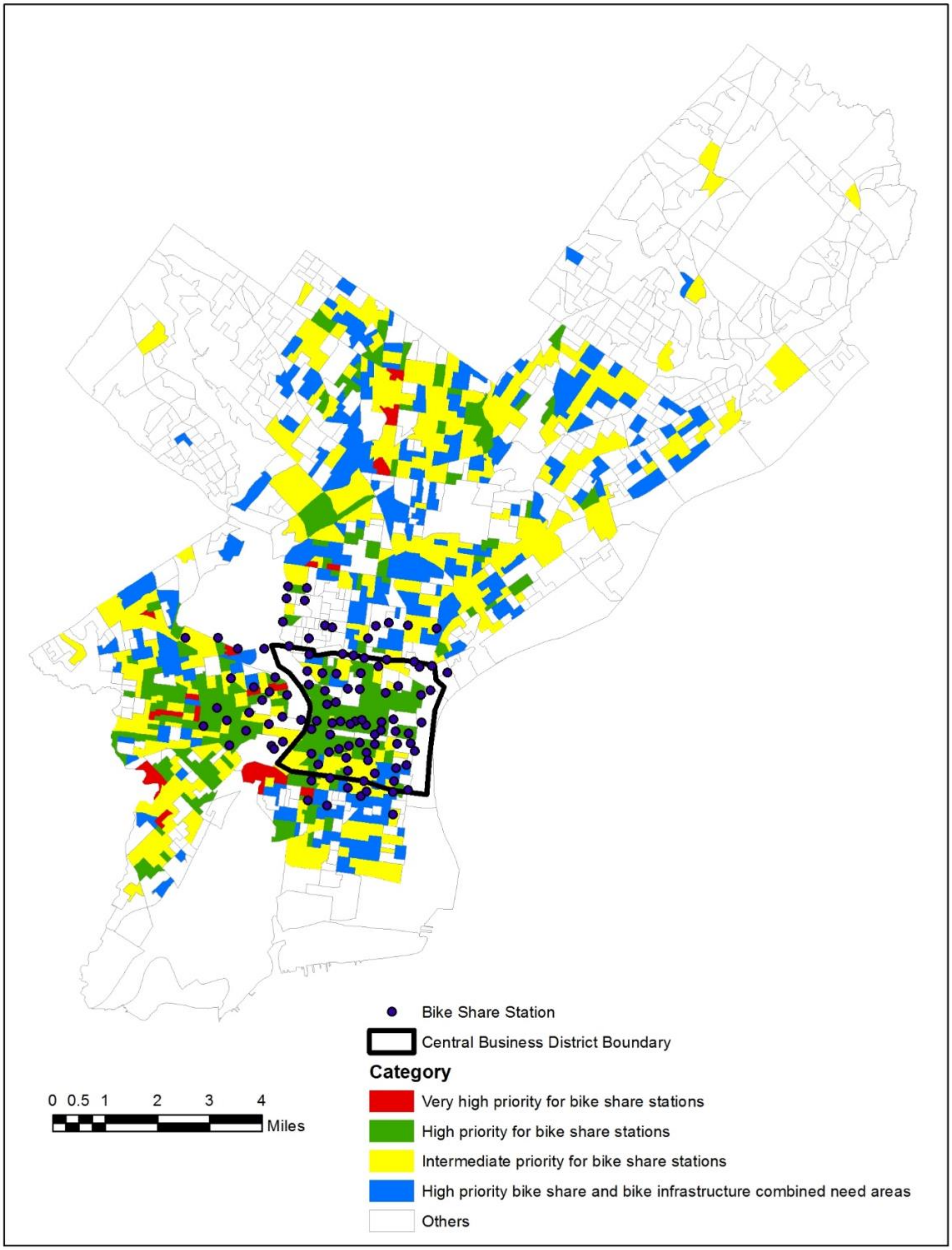


Figure 20. Map of current bikeshare stations and block group classifications in Chicago and Philadelphia

Conclusion

Bikeshare programs can play an important role in sustainable transportation systems by offering a viable mode choice for many types of last mile trips. However, recent bikeshare systems are targeting more affluent and white-dominated areas. To address this problem, our research has developed a new index, which can identify bikeshare station locations providing high potential accessibility improvement to jobs and essential services for underserved communities. Our research has uncovered the fact that most of the current bikeshare stations in Chicago and Philadelphia are not located in priority areas for bikeshare stations. Only 0.3% (Chicago) and 1.0% (Philadelphia) of bikeshare stations are in areas with very high priority for bikeshare stations. There is a considerable proportion of bikeshare stations (10.0% in Chicago and 5.7% in Philadelphia) in areas with high priority for bikeshare and bike infrastructure combined need areas. This reflects that the level of bike infrastructures still needs to be improved to support bikeshare systems. Bikeshare systems should pay more attention to those underserved areas, where are “bikeshare desert”.

Based on our quantitative analysis, bikeshare system can produce substantial accessibility improvements for underserved communities. From the perspective of absolute accessibility change, average accessibility improvements for underserved communities are greater than those experienced in well-served areas (Figure 13). This phenomenon is more obvious when bicycle infrastructure levels are low and moderate (Figure 16). From another point of view, the proportion of block groups in underserved communities with an accessibility increase is greater than that of block groups in adequately served areas (Figure 18). Residents from underserved communities can indeed benefit from bikeshare systems, and the average benefits are more significant in underserved areas than that in adequately served communities. Our index can also inform the siting of bikeshare stations to better serve low-income populations, people of color, and transit-dependent residents.

Appendix

We ranked all 34 candidate cities in every category, and the ranking results are shown in the following figures and tables. For the first category data, we want to make sure that the candidate cities are large enough to implement and support a bikeshare program in underserved communities. We ordered cities first by population and then by city land area (square mile) (Table 16). We also highlighted the two cities selected in the red color rectangles (Figure 21).

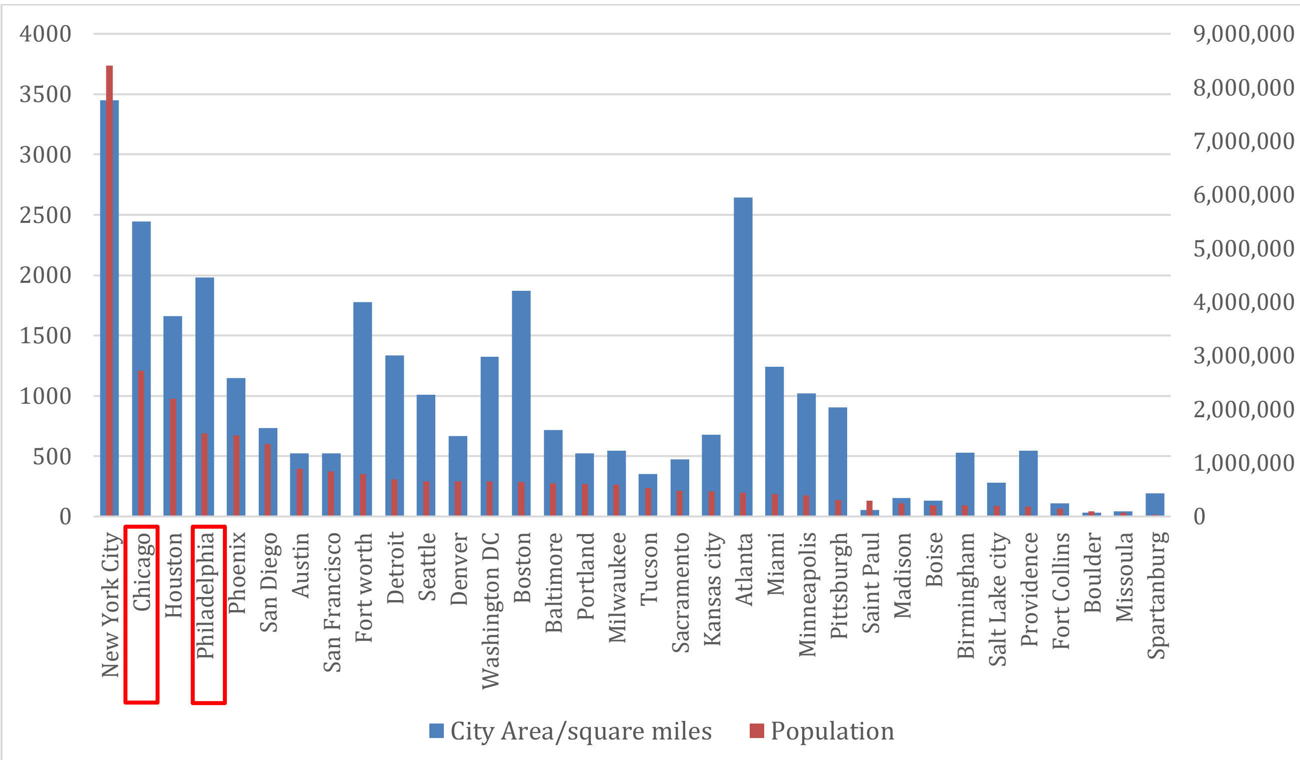


Figure 21. City area and population ranking

Table 16. Area and population data for top ten cities

State	City	City area/ Square miles	Population
New York	New York City	3450	8,406,000
Illinois	Chicago	2,443	2,719,000
Texas	Houston	1660	2,196,000
Pennsylvania	Philadelphia	1981	1,553,000
Arizona	Phoenix	1147	1,513,000
California	San Diego	732.4	1,355,896
Texas	Austin	523	885,400
California	San Francisco	524	837,442
Texas	Fort Worth	1779.1	792,727
Michigan	Detroit	1337	688,701

In the aspect of income and ethnicity, our primary focus is on underserved communities, which means there needs to be a high enough total underserved population (using percent race as a proxy). We ranked the cites first, by Black and Hispanic race percentage and then by median household income (Table 17). Figure 22 shows the ranking of all 34 cities in median household income and race percentage. We also highlighted the two cities selected in the red color rectangles.

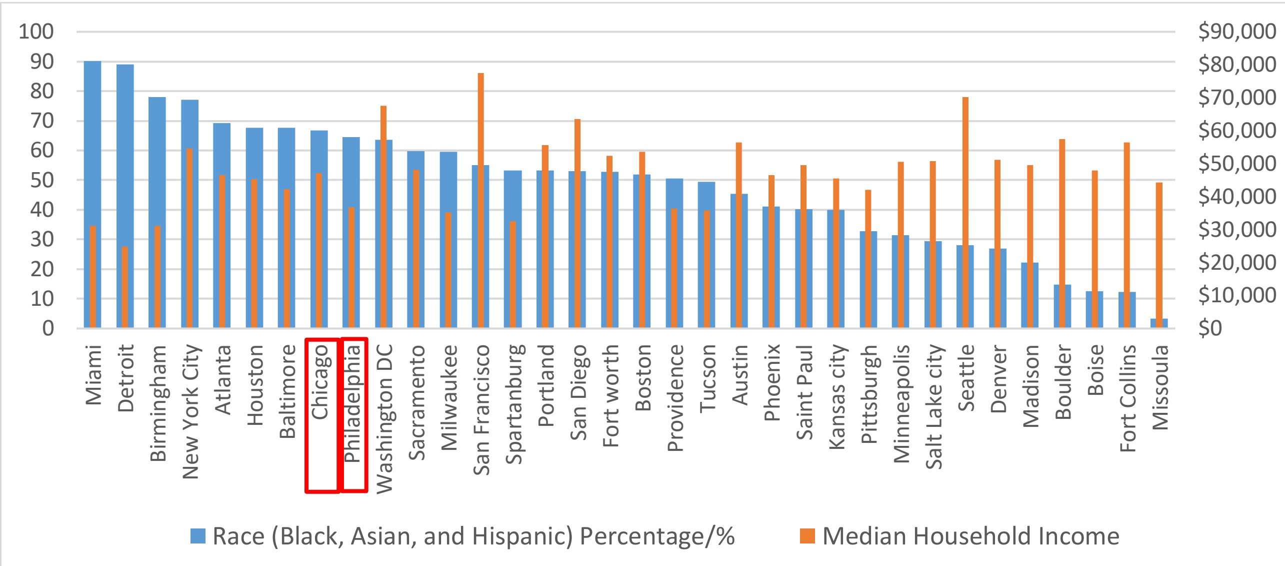


Figure 22. City Median Household Income and Race (Black, Asian, and Hispanic) Percentage Ranking

Table 17. Median household income and race (Black, Asian, and Hispanic) percentage data for top ten cities

State	City	Race (Black, Asian, and Hispanic) percentage/%	Median household income
Florida	Miami	90.2	$31,070
Michigan	Detroit	89.1	$24,820
Alabama	Birmingham	78	$31,152
New York	New York City	77.1	$54,700
Georgia	Atlanta	69.3	$46,485
Texas	Houston	67.6	$45,353
Maryland	Baltimore	67.57	$42,266
Illinois	Chicago	66.7	$47,099
Pennsylvania	Philadelphia	64.4	$36,836
D.C.	Washington D.C.	63.5	$67,572

We want a high percentage of household without vehicles and low car ownership per household (Table 18). Figure 23 shows the ranking of all 34 cities in car ownership. We also highlighted the two cities selected in the red color rectangles.

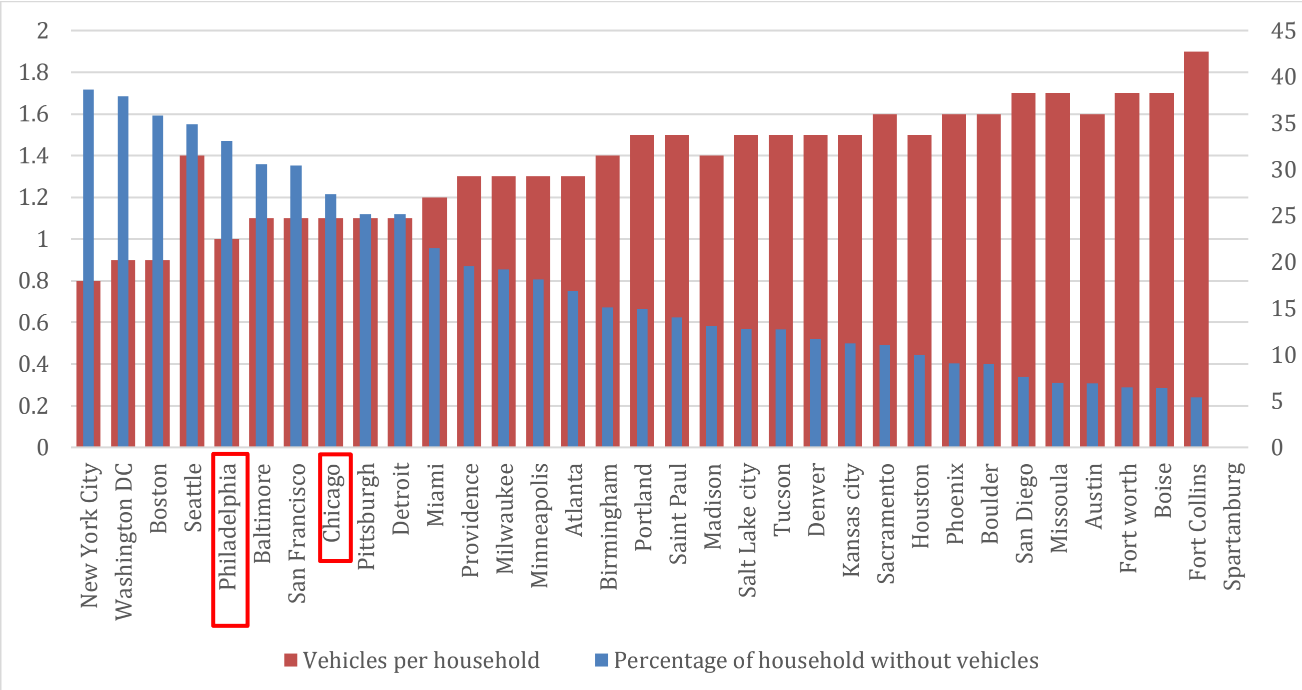


Figure 23. City Percentage of Households without Vehicles and Number of Vehicles per Household

Table 18. Percentage of households without vehicles and number of vehicles per household data for top ten cities

State	City	Household has no vehicles/%	Vehicle per household
New York	New York City	38.6	0.8
DC	Washington DC	37.9	0.9
Massachusetts	Boston	35.8	0.9
Washington	Seattle	34.91	1.4
Pennsylvania	Philadelphia	33.1	1
Maryland	Baltimore	30.6	1.1
California	San Francisco	30.4	1.1
Illinois	Chicago	27.3	1.1
Pennsylvania	Pittsburgh	25.2	1.1
Michigan	Detroit	25.2	1.1

If a city has more bikeshare stations, there is an opportunity for expansion of the existing bikeshare system to serve the underserved communities. So, for this factor, we ranked cities first, by the number of bike stations and then by a bike-friendly ranking index, which comes from the "Bicycle Friendly Community" rankings. We also considered the bike infrastructure: protected bike lane, availability of bike rack on bus or metro system. The overall ranking results for the first ten cities are listed in Table 19. We also highlighted the two cities selected in red color.

Table 19. Top ten cities in bike infrastructure ranking

State	City	Friendly Rankling	Bike Station Number	Public Bus/Bike rack available	Light Rail or Metro/ Bike rack available	Protected Bike Lane
New York	New York City	11	600	Yes	light Rail / Yes	Yes
Illinois	Chicago	14	581	CTA / Yes	Washington Metro / Yes (but only allow in rush period)	Yes
DC	Washington DC		459	Metrobus / Yes	Train or light rail / Yes (only off rush hour)	
Minnesota	Saint Paul	2	190	MetroTransit / Yes	Metro	
Massachusetts	Boston	4	140	MBTA Bus / Yes	MBTA (Some available)	Yes
Oregon	Portland	6	100	TriMet / Yes	Trolley car (Only one bike capacity in rush hour)	
California	San Diego	8	100	San Diego Metropolitan Transit System / Yes	Light Rail / Yes	Yes
Pennsylvania	Philadelphia	12	105	SEPTA / Yes	Light Rail (full-size bike is not allowed) / Bay Area Rapid Transit	Yes
Colorado	Denver	7	87	RTD / Yes	Metrorail / Yes	Yes
California	San Francisco	8	84	Golden Gate Transit / Yes	only center Monorail / No	Yes

Note: blank means the data is not available.

Considering the weather factors, we sorted them by the order of average annual precipitation days (from few to many), average annual precipitation inch (from small to big), average temperature in July (from low to high), and average annual snowfall inch (from small to big) (Table 20).

Table 20. Top ten cities in weather and climate ranking

State	City	Jan Temp	April Temp	July Temp	Oct Temp	Average annual Precipitation /inch	Average annual Precipitation /days	Average annual Snowfall (in.)
Arizona	Phoenix	54.2	70.2	92.8	74.6	8.29	36	-
California	San Diego	57.8	62.6	70.9	67.6	10.77	41	-
Arizona	Tucson	51.7	66	86.5	70.5	12.17	53	1.2
California	Sacramento	46.3	58.9	75.4	64.4	17.93	58	-
California	San Francisco	49.4	56.2	62.8	61	20.11	63	-
Texas	Fort Worth	44.1	65	85	67.2	34.73	79	2.6
Colorado	Fort Collins	31.1	41.5	66.5	50.1	16.05	81	57
Texas	Austin	50.2	68.3	84.2	70.6	33.65	85	0.9
Idaho	Boise	30.2	50.6	74.7	52.8	12.19	89	20.6
Colorado	Denver	29.2	47.6	73.4	51	15.81	89	60.3

Note: "-" means the data is not available.

To obtain the overall rankings of all candidate cities, we recruited sixteen experts from five different fields (bikeshare academics, bikeshare companies, metropolitan planning organization (MPO), bike advocates, and local city government) to participant in a three-round Delphi test to select our case study cities. The list of all the sixteen experts is shown in Table 21. This expert panel helped us identify the importance of different data categories with their valuable knowledge and experiences.

Each participant went through a round-robin exercise to establish weights for every data category that correlate to both bikeshare provision and equitable access. These weights were used to identify which cities we would use in the remainder of our study. The weight setting exercise was conducted online. The weights setting results for every round are shown below in Table 22.

As we can see, the weights setting converges in the first round and there is not much change of the weights setting in the following rounds. Some experts didn't change their weights setting a lot in every round, which means that they were not affected by other experts' decisions and wanted to insist on their original settings. Some experts gave their opinions on weight setting.

Table 21. Delphi test experts list

Group	Name	Organization	Department or Position
Bicycle Academics	Susan Handy	University of California, Davis	Department of Environmental Science and Policy
	Jennifer Dill	Portland State University	Nohad A. Toulan School of Urban Studies and Planning
	Alex Karner	Georgia Institute of Technology	School of City and Regional Planning
	Lisa Aultman-Hall	University of Vermont	School of Engineering/Transportation Research Center
Bikeshare Company	Dani Simons	Motivate	Director of Corporate Communications & External Affairs at Motivate
	Paul DeMaio	Metro Bike	Founder of MetroBike, LLC
MPO	Sam Shelton	Sacramento Area Council of Government	Senior Planner
	Heath Maddox	San Francisco Municipal Transportation Agency	Project Manager
	Kimberly Lucas	Capitol Bikeshare Program	District DOT Director
	Darren Buck	Capitol Bikeshare Program	District DOT Director
	Henry Dunbar	Capitol Bikeshare Program	BikeArlington Program Director
Bike Advocates	Jim Brown	Sacramento Bay Area Advocates	Executive Director
	Jeanie Ward-Waller	California Bicycle Coalition	Policy Director
	Steve Clark	National League of American Bicyclists	Bicycle Friendly Community Specialist
Local City	Jennifer Donofrio	City council, Davis, CA	Bike and Pedestrian Coordinator for Davis
	Robb Davis	City council, Davis, CA	Mayor

Table 22. Weight setting summary for every round

Category		City area and population	Median household income and Race percentage	Car ownership	Bike infrastructure	Weather and climate	Sum
Round 1	Average	18.8	25.8	15.4	34.2	5.8	100
	SD*	12.4	11.5	11.8	28.8	5.7	
Round 2	Average	18.9	24.6	15.4	35.4	5.7	100
	SD*	13.0	10.43	12.3	25.9	5.0	
Round 3	Average	18.9	26.1	16.1	33.9	5	100
	SD*	13.0	11.0	12.2	26.2	5	

Note "SD" is short for standard deviation

Expert 1:

I believe the demand for bikeshare system service is more closely related to city area/pop demographics and medium household income. So, I weighted those factors higher. I also believe that latent demand for bikeshare is hidden behind poor bike/pedestrian and transit planning decisions as well as cultural issues with notions of cycling (i.e., that's for people with spandex).

Expert 2:

In studying equity, I think the race and income data should be weighted most heavily. Area and population should indicate density of the city, which is also a critical factor in considering the potential for bikeshare use.

Expert 3:

I find that bike infrastructure and basic bike-friendly design (which would encourage reduced car ownership) are key to providing equitable transportation.

Expert 4:

Where I live, median income and bike infrastructure correlate - lower income neighborhoods typically use bikes for everyday travel at a higher rate (also reflected by low car ownership) but have less bicycle infrastructure. So success for an equitable bikeshare system requires adequate infrastructure.

Their weights setting results strongly support their opinions above. Income and bike infrastructure play an important role in the final city selection. Based on the final weights the experts reached in last round Delphi test, we calculated the overall scores for all candidate cities and selected Chicago and Philadelphia.

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