Dock-based and Dockless Bikesharing Systems: Analysis of Equitable Access for Disadvantaged Communities

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A Research Report from the National Center for Sustainable Transportation

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16. Abstract

Dockless bikeshare systems show potential for replacing traditional dock-based systems, primarily by offering greater flexibility for bike returns. However, many cities in the US currently regulate the maximum number of bikes a dockless system can deploy due to bicycle management issues. Despite inventory management challenges, dockless systems offer two main advantages over dock-based systems: a lower (sometimes zero) membership fee, and being free-range (or, at least free-range within designated service areas). Moreover, these two advantages may help to solve existing access barriers for disadvantaged populations. To date, much of the research on micro-mobility options has focused on addressing equity issues in dock-based systems. We have limited knowledge of whether, and the extent to which dockless systems might help mitigate barriers to bikeshare for disadvantaged populations. Using San Francisco and Los Angeles as case studies, because both cities have both dock-based and dockless systems running concurrently, we quantify bikeshare service levels for communities of concern (CoCs) by analyzing the spatial distribution of service areas, available bikes and bike idle times, trip data, and rebalancing among the dock-based and dockless systems. We find that dockless systems can provide greater availability of bikes for CoCs than for other communities, attracting more trip demand in these communities because of a larger service area and frequent bike rebalancing practices. More importantly, we notice that the existence of electric bikes helps mitigate the bikeshare usage gap between CoCs and other tracts. Besides the data analyses for bikeshare trips, we also study the spatial distribution of online suggested station locations and find that the participants' desired destinations for work/school purposes have not been covered to the same extent in CoCs as in other communities. Our results provide policy insights to local municipalities on how to properly regulate and develop dockless bikeshare systems to improve mobility equity.

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Disclaimer

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NCST

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EXECUTIVE SUMMARY

Bikesharing systems have been increasing in popularity because they offer access to a bicycle without owning it. Currently, there are two main types of systems, those that are based on stations to pick-up and drop-off the bikes (i.e., dockbased systems), and dockless or free-floating systems. While the number of bikeshare trips are increasing, there are concerns and uncertainty about equitable access (e.g., bike trip demand, bike availability, station network, costs) to this mode. The authors have conducted extensive research analyzing some of these factors (e.g., trip demand, trip distribution, and optimal design of station networks) and have shown evidence of several equity issues with respect to bikesharing access in disadvantaged communities. In this study, the authors concentrated on analyzing the comparative performance of dock-based and dockless bikesharing systems and how each type of system could help overcome some of the challenges to improve accessibility in and to disadvantaged communities.

The study uses the cities of San Francisco and Los Angeles as case studies because both types of systems are currently operating there, and data was available for the analyses, although there were significant service and market changes due to COVID-19. Ford GoBike (dockbased) and JUMP Bike (dockless) operate in San Francisco, while Metro Bike (dock-based) and JUMP Bike (dockless) operate in Los Angeles. Specifically, the analyses include multiple metrics such as the spatial distribution of service areas, available bikes and bike idle times, trip data, and rebalancing among dock-based and dockless systems. The main findings are as follows:

Service Area. In San Francisco, the analyses showed that the dockless bikeshare system tends to cover more area and a larger population of communities of concern (CoCs), a local classification of disadvantaged communities, than the dock-based system. Users of dockless bikeshare can pick up or return bikes in CoCs as long as the CoCs are situated within the service area. In Los Angeles, the two systems behave rather differently. The dockless JUMP bike has a larger service area in both non-CoC and CoC tracts, but it has most of it bikes deployed in Santa Monica and surrounding coastal areas, which are both rich communities and tourist attractions. The dock-based Metro Bike has more bike stations and operations in downtown Los Angeles.

Bike Availability. In San Francisco, for JUMP Bike, the number of available bikes is, on average, greater in CoCs than in non-CoCs. JUMP Bike keeps an average of nearly 32.5% of its bikes in CoCs since its launch in 2018 and the average idle time within CoCs is shorter than that of non-CoCs. In LA, since the JUMP service area is generated from idling bikes in the region, some of the regions can have a very limited number of bikes, causing the large variation in bike availability and idling times in JUMP. Nonetheless, JUMP has managed to provide better service in non-CoC communities, while Metro Bike Share has a more equal service for all tracts. There is no significant difference between dock-based and dockless systems regarding trip durations.

Bike Rebalancing. After analyzing JUMP Bike activities in San Francisco, we find that a greater proportion of rebalancing activities happen in CoCs for JUMP Bike than for Ford GoBike. JUMP Bike produces a comparable level of bike availability in CoCs as Ford GoBike considering JUMP Bike's greater service area and smaller bike fleet size. We also find that there are a certain number of users starting or ending their trips in CoCs, but outside the approved service area, which demonstrates potential demand.

Summary (see Table ES-1 for a summary of the comparative analyses). In both cities, San Francisco and Los Angeles, we can see that dockless bikeshare systems cover more tracts, including tracts identified as disadvantaged communities, than dock-based systems. However, there is a slight difference in dockless bikeshare systems serving CoCs between San Francisco and Los Angeles. The dockless system in San Francisco serves CoCs better than the dock-based one, while the situation is reversed in Los Angeles. One possible reason for this is the different nature of the two regions: San Francisco is a very compact city, where bike users can travel across all tracts with few obstacles, engaging in more activities across regions; on the other hand, the Los Angeles metro area has a relatively extended urban layout, making it extremely difficult to travel across different regions by bike, therefore activities are mostly restricted by where the bikes are deployed. Another reason is that the permitted service area of JUMP Bike in Los Angeles mainly covers the Santa Monica region, where there are limited disadvantaged populations.

Even though the local government designates the service areas of both systems, the dock-based system can cover more CoC areas if the municipal government allows expanded coverage, and if the company is willing to site stations in the CoCs. Dockless systems still have the advantage of not requiring physical stations. Thus, local governments should allow the permitted service area of dockless bikeshare systems to cover more CoCs when introducing new bikesharing services. From our quantitative analyses, we believe that dockless bikeshare systems could solve equity problems through a broadened service area and frequent rebalancing. However, there remain regulatory issues around dockless bikeshare systems, including how to manage them and how many bikes should be allowed? Dockless bikeshare companies should work together with local governments to design a dedicated plan to extend the system scale incrementally. Our results and methodology can assist local governments in monitoring dockless systems in terms of serving CoCs as they expand and in providing timely regulation requirements of private bikeshare companies. Moreover, suggestions for future promotion of dockless bikeshare in CoCs could include the integration of an in-person enrollment option for the affordable membership plan and keeping this fee as affordable as possible for CoCs. Community outreach activities should be used in advertising to users in CoCs since they may have limited access to the internet and smartphones.

Additionally, using crowdsourced suggestions from online platforms, we also conduct a comparative assessment of current station locations with the users' suggestions of potential station locations. The analyses also illustrate the potential of dockless bikeshare systems to cover demand gaps for CoCs, communities which are not sufficiently covered by dock-based systems.

Table ES-1. Evaluation of two bikeshare systems in San Francisco.

	Systems	Ford GoBike (dock-based) and JUMP Bike (dockless)
San Francisco	Service area	JUMP Bike covers twice areas as large as Ford GoBike within the boundary
	Bike availability/idling	1. The same or even greater level of bike availability in CoCs in JUMP Bike after calibrating bike number and service area 2. Bike idling time is shorter through frequent rebalancing in JUMP Bike
	Bike rebalancing	A greater proportion of bike rebalancing activities are related to CoCs in JUMP bikes
	Bike trips	1. Almost the same level of trip generated or terminated within CoCs between Ford GoBike and JUMP Bike 2. Longer trip time because of flexibility in JUMP Bike 3. E-bikes in JUMP Bike may help mitigate the barriers faced by bikeshare users from CoCs
Los Angeles	Systems	Metro Bike Share (dock-based) and JUMP Bike (dockless)
	Service area	1. JUMP Bike covers significantly larger area (both CoC and non-CoC) than Metro Bike Share. 2. The two systems have different most-served areas: JUMP has most of its bikes deployed in the Santa Monica area where mostly rich communities are located; Metro Bike Share has three clusters of stations, with one of the clusters located in downtown Los Angeles where most disadvantaged communities are located.
	Bike availability/idling	1. For bike availability, both Metro Bike Share and JUMP have larger number of bikes in non CoC tracts than in CoC tracts. 2. For bike idling time, Metro Bike Share has more consistent time variation in CoC tracts and non-CoC tracts; JUMP has larger variations in non-CoC tracts than in CoC tracts.
	Bike rebalancing	The rebalancing activities in both systems follow a similar pattern: the areas with most bikes rebalancing out are also the areas with most bikes rebalancing in.
	Bike trips	1. Metro Bike Share has a more even distribution in number of bike trips between CoC tracts and non-CoC tracts. JUMP bike has disproportionally more trips in non-CoC tracts. 2. Both systems have similar trip durations.

By comparing the spatial distributions of current stations and suggested locations, we can identify the demand gaps in CoCs due to the space restriction of dock-based bikeshare systems. In CoC areas, the leading purpose of suggested stations is work/school, while the current dock-based stations have not sufficiently covered that bikeshare demand. Dockless bikeshare systems, without restrictions in service areas, could address this limitation of dock-based bikeshare systems. Local governments could leverage this online platform to regulate the planning of dockless bikeshare systems to cover potential demand in CoCs. Moreover, it is important to acknowledge the bias of this online platform because low-income or disadvantaged communities are underrepresented. An equitable design of bikeshare systems needs more voices from the traditionally underrepresented populations.

Last, participation in the online suggestion platform is not as high as expected. This problem might be overcome with a continuous promotion or outreach effort. Continuous participation is important because feedback is dynamic, and topics of concern change over time. In addition, planners or service providers must have the capacity to interpret the crowdsourced data and turn it into practical actions.

Introduction

Bikeshare, as a non-motorized transportation service, is an increasingly prevalent transportation option that offers users access to a bicycle without owing it (NACTO 2018). There are two types of bikeshare systems: dock-based and dockless (or free-floating). A dock-based bikeshare requires that users return bikes to a fixed station with multiple bike docks. Currently, dock-based bikeshare systems are the dominant system across the U.S. Dockless bikeshare users do not need to anchor a bike to a station, and instead, for greater convenience, can return a bike along a roadside within a designated area.

In 2017, dockless systems proliferated across the U.S. because several international dockless bikeshare companies extended their markets in North America. However, the rapid growth without efficient regulations and planning resulted in cluttered streets with broken bikes, which was similar to the initial experiences with this mode in many Chinese cities where large numbers of bikes were dumped (Wilke and Lieswyn 2018). After that early exponential growth period, dockless bikeshare systems returned to a slow-growth phase under government regulations in 2018 and 2019. Overall, trip demand from dockless systems has increased slowly since. In 2018 for instance, there were about 45.5 million bikeshare trips in the U.S., with 9 million (about 20%) using dockless bikeshare systems (NACTO 2019).

Even though trips from dock-based systems represent a significant number of trips, recent research has identified equity issues with respect to the station structure (e.g., distribution of stations and boundary of the serviced market) and accessibility (e.g., financial barriers in low-income communities) (McNeil et al. 2017; Qian and Niemeier 2019). Among these barriers, the most frequently mentioned is the availability of bikes. In dock-based bikeshare systems, the availability barrier exists in the form of the absence of bikeshare stations within walking distance (Bernatchez et al. 2015) and not enough bikes in stations (Médard de Chardon, Caruso, and Thomas 2016). Bike availability at stations can be solved by efficient bike rebalancing operations. Enough bikes in stations can also be solved by sufficient bike rebalancing operations. These barriers intensify in disadvantaged areas, as noted by Qian and Jaller (2021). Therefore, our analyses focus on the performance of both bikeshare systems in serving disadvantaged communities in reference to service areas, bike availability, bike idling, rebalancing operations, and bikeshare trip demand.

By design, dockless systems with no spatial distribution restrictions and low membership fees could improve accessibility and help mitigate dock-based systems' limitations. However, considering the unsuccessful experiences in China, local governments are hesitant about dockless systems, even though they could provide improved mobility options and address equity barriers for disadvantaged and underserved communities and communities of concern (CoCs) (MTC 2018). The objective of this work is to conduct a quantitative analysis to compare the service levels between dock-based and dockless systems and provide planning recommendations. The study uses the cities of San Francisco and Los Angeles as case studies because both types of systems are currently operating there, and data is available for the analyses. Specifically, the analyses include multiple metrics: the spatial distribution of service areas, available bikes and bike idle times, trip data, and rebalancing among dock-based and dockless systems. In addition, using crowdsourced suggestions from online platforms, we also conduct a comparative assessment of current station locations with the users' suggestions of potential station locations. The analyses also illustrate the potential of dockless bikeshare systems to cover demand gaps for CoCs, communities which are not sufficiently covered by dock-based systems.

Literature Review

Bikeshare and Equity

Recent research analyzes the equity problems faced by dock-based bikeshare systems which can be divided into two streams: social equity and spatial equity (Hirsch, Stratton-Rayner, et al. 2019). In terms of social equity research, researchers analyze bikeshare users' profiles, including the users' demographic information and their trip features (e.g., trip purposes), generally using survey data (McNeil et al. 2017; Buck 2013; Bernatchez et al. 2015). The social equity studies tend to focus on existing barriers faced by disadvantaged populations, e.g., cultural and financial barriers, or limited or no availability of bikeshare stations within walking distance (Bernatchez et al. 2015; Cohen 2016; McNeil, Broach, and Dill 2018; Smith, Oh, and Lei 2015; Ursaki and Aultman-Hall 2015; M. Winters and Hosford 2018).

Spatial equity research has focused on the spatial distribution of bikeshare stations and bikeshare demand trip generation. Overall, results show a deficit of bikeshare stations in disadvantaged areas, and that properly designed bikeshare systems can provide the same or an even greater level of accessibility for disadvantaged areas than for other areas (Qian and Niemeier 2019). Additionally, studies have shown an uneven distribution of bikeshare demand between disadvantaged areas and other areas, for example, for Chicago's system (Cohen 2016; Qian and Jaller 2020).

There is a limited number of studies focusing on equity problems for dockless systems. Hirsch, Stewart, Ziegler, Richter, and Mooney (2019) analyze the personal characteristics of users who reported using dockless bikeshare through a survey study with 601 participants in Seattle. They find that users of dockless bikeshare tend to be young, male, white, and better educated, which is consistent with dock-based bikeshare. They also suggest, though with limited evidence, that dockless bikeshare systems could potentially remove inequitably distributed barriers if cities, researchers, and operators work together in shaping this new shared mobility. Similar to the previous research, Mooney et al. (2019) find a modest level of inequities in bikeshare access across different demographic populations, and they think that dockless bikeshare systems hold the potential to remove access barriers faced by disadvantaged populations. However, to our knowledge, the literature has not compared the equitability of dock-based and dockless systems, especially in systems operating at the same time.

Online Suggestions for Bikeshare Planning

Web-based crowdsourcing has been discussed a lot in the general planning process (Afzalan and Muller 2018; Borges, Jankowski, and Davis 2015; Brabham 2009; Pánek and Pászto 2017; Seltzer and Mahmoudi 2013). In transportation planning, this technology has also been applied in transit planning (Brabham 2012; Brabham, Sanchez, and Bartholomew 2009) and active transportation (Afzalan and Sanchez 2017; Griffin and Jiao 2019a; 2019b; Krykewycz et al. 2011; Piatkowski, Marshall, and Afzalan 2017). Considering the scope of this paper, we focus on its application in bikeshare planning.

Since web-based crowdsourcing includes both text contents and geospatial information for suggested locations, research regarding its application in bikeshare planning includes content analysis and spatial analysis. For the spatial analysis, there are multiple researchers analyzing geospatial locations by online suggestions. Afzalan & Sanchez (2017) find that the new bikeshare station locations suggested online are almost the same as what had been previously decided by local planners. However, there are still some unexpected suggestions for locations outside the targeted areas. Griffin & Jiao (2019a) conduct two spatial analyses for suggested locations: a proximity analysis and Moran's I examination. The proximity analysis shows that less than 10% of suggestions are within 100 feet (30m) of built stations. However, another spatial analysis (using Moran's I to test for spatial auto-correlation) shows that the suggested locations and built ones show significant clustering, a result which differs from their proximity analysis (Griffin and Jiao 2019a). The reason for Griffin & Jiao (2019a)'s different outcomes may be that the 100 feet buffer range for proximity analysis is too small. In the end, Griffin & Jiao (2019a) conclude that online suggestion platform data can influence the planning process to some extent. For the content analysis, Afzalan & Sanchez (2017) analyze the content provided by participants. Their analysis shows that 83.5% of the content falls into the accessibility category, i.e., having access to desired destinations (e.g., restaurants or hotels). This statistic indicates that bikeshare is a reliable transport mode to improve accessibility, as evidenced by Qian and Niemeier (2019) and Qian and Jaller (2021).

Regarding how the information retrieved from these crowdsourcing data can be applied to direct bikeshare planning, the attitudes towards its great potential to facilitate bikeshare planning are mixed. Afzalan & Sanchez (2017) find conflicting opinions from local planners. As we might expect, most researchers and local planners express affirmative opinions on the efficiency of this technology (Griffin and Jiao 2019b). A negative attitude towards this online technology is that it can only show if the public has paid attention to the planning process but they have no influence on the planning decision. Thus, Afzalan & Sanchez (2017) point out the use of crowdsourcing data is highly dependent on the capability of local planners. If they have the knowledge to interpret the meaning of such a great amount of online suggestions, this will facilitate the planning process (Afzalan and Sanchez 2017). Bugs et al. (2010) develop an online participation GIS platform, and note that from the feedback received, they find the platform easy-to-use and they feel great satisfaction and excitement about contributing to the planning processes.

Study Area and Data Description

Communities of Concern (CoCs)

There is not a unified definition of disadvantaged populations or underserved communities across different regions in the US. Our previous study defines disadvantaged communities based on income, percentage of minority populations, and vehicle ownership (Qian and Niemeier 2019).

San Francisco

In San Francisco, the MTC provides its own definition of disadvantaged communities for the transportation field. In a recent report evaluating dockless bikeshare in San Francisco, the SFMTA uses the MTC definition when conducting equity analyses (MTC 2018). The MTC terms and identifies disadvantaged populations as "Communities of Concern (CoCs)" based on the 2012-2016 American Community Survey (ACS) 5-year tract-level data. There are eight factors considered in the classification system (see Table 1).

Specifically, a census tract will be identified as a CoC if its "Low-Income" and "Minority" shares are over the threshold values, or if its "Low-Income" and three or more variables (excluding "Minority") shares exceed the threshold values. According to the definition, we provide two examples of CoCs to better explain the term. The first example of a CoC is a census tract with 80% (>70%) of the population self-identified as minority and 40% (>30%) of the households make under 200% of the Federal poverty line. Another example of CoCs is a census tract that has 40% (>30%) low-income households and 30% (>20%) of the population with limited English proficiency, 20% (>10%) zero-vehicle households, 20% (>10%) of the population over 75 years old.

Comparing MTC's with other disadvantaged community definitions, MTC has more considerations besides income, minority race, and vehicle ownership, such as English proficiency. The reason for this may be that California has many immigrant populations that are more likely to include minority races. If a city does not have a definition of disadvantaged communities, it can adopt the definition from previous analyses (Qian and Niemeier 2019). Although we use the CoC definition here, the methods described in this research can be implemented in other cities using their own classifications.

In total, we identified 52 census tracts as CoCs from the 194 census tracts in the city (Figure 1). Furthermore, within the CoCs, the MTC classifies communities as of high (32), higher (3), and highest (17) concern. If a city adopts our previous definition of disadvantaged communities, it can also further classify disadvantaged communities into high, higher, and highest.

Table 1. Factors Used to Classify CoCs.

Disadvantaged factor	Disadvantaged Factor Definition	Concentration Threshold
Minority	Minority populations include American Indian or Pacific Islander Alone (Non-Hispanic/non-Latino); Asian Alone (non-Hispanic/non-Latino); Black or African-American Alone (non-Hispanic/non-Latino); and Other (Some Other Race, Two or More Races)	70%
Low Income (< 200% Federal Poverty Level -FPL)	A person living in a household with incomes less than 200% of the federal poverty level	30%
Limited English Proficiency	A person above the age of 5 years, who do not speak English at least "well" as their primary language or had a limited ability to read, speak, write, or understand English at least "well"	20%
Zero-Vehicle Household	Households that do not own a personal vehicle	10%
Seniors 75 Years and Over	Self-explanatory	10%
People with Disability	Self-explanatory	25%
Single-Parent Family	Self-explanatory	20%
Severely Rent-Burdened Household	Self-explanatory	15%

Los Angeles

Since different areas have their customized disadvantaged populations, we adopt a different definition of CoCs in Los Angeles, which is provided by the Southern California Association of Governments (SCAG) from its Plan Performance Environmental Justice Technical Report. In the report, SCAG investigated all Census Designated Places (CDPs) and City of Los Angeles Community Planning Areas (CPAs) and selected regions that fall in the top 33% of all communities in SCAG region for having the highest concentration of minority populations and low-income households (Southern California Association of Governments 2020). A person is classified as "minority" if the individual self-identified as one of the minority groups in the census (Table 2). SCAG performed poverty classification according to the income guidelines outlined by the U.S. Department of Health & Human Services.

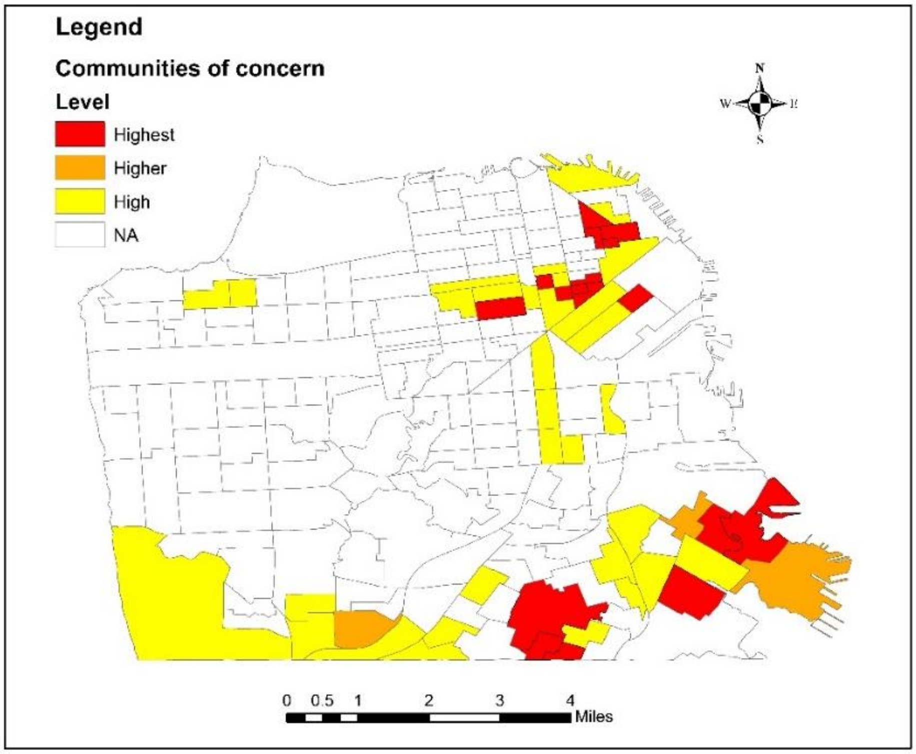

Figure 1. Map for CoCs in San Francisco.

Table 2. Factors used to classify CoCs by SCAG

Disadvantaged factor	Disadvantaged Factor Definition	Concentration Threshold*
Minority	Minority populations include African American, Hispanic, Asian/Pacific Islander, and Native American, Alaskan Native and Other (Some Other Race, Two or More Races)	33%
Low Income Households	SCAG chose the poverty level according to federal guideline and regional average household size for a given census year. For example, the poverty threshold for a family of three is $19,105 in 2016.]	33%

Note: * The concentration threshold is different from the standard used for San Francisco. A SCAG region meets the threshold if both of its concentrations in minority population and low-income households meet the threshold.

SCAG used the "community-based approach," similar to the Bay Area's Metropolitan Transportation Commission (MTC), but made some adjustments to make the approach suitable for the region. Figure 2 shows the distribution of CoCs within the case study area. From the figure, it is apparent that most of the CoCs are located in the center of the Los Angeles metro area.

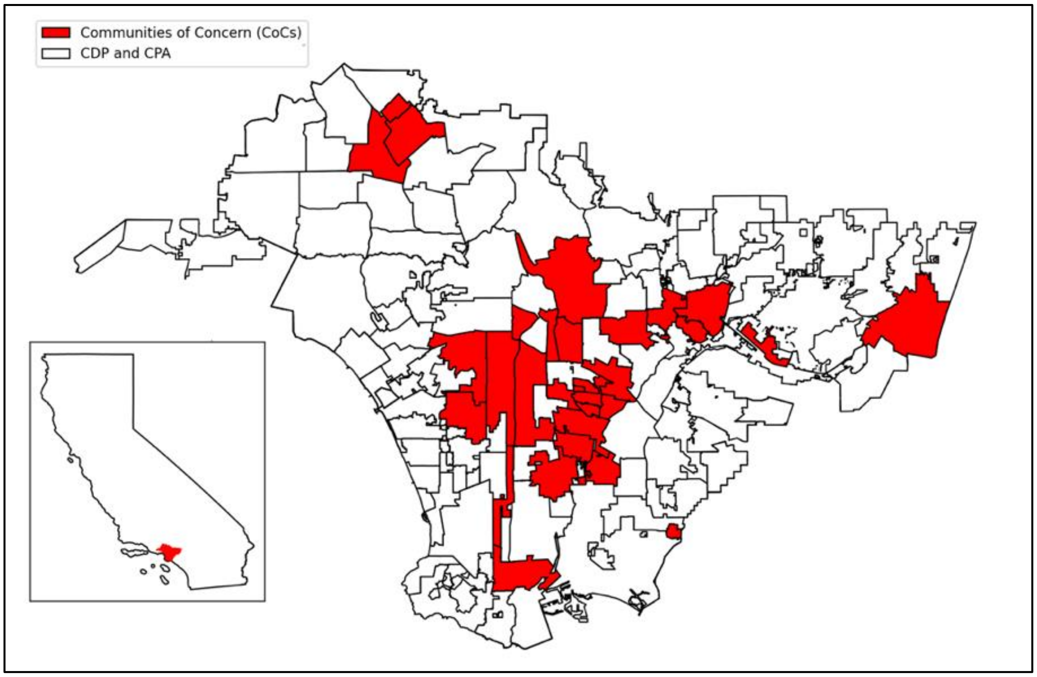

Figure 2. Maps for CoCs in Los Angeles.

Case Study City and Bikeshare Systems

San Francisco

This research uses San Francisco as a case study area, considering it has both dock-based (Ford GoBike) and dockless (JUMP Bike) bikeshare systems operating concurrently. The Ford GoBike, operated by Motivate, is a dock-based system that has been in operation since 2013, which provides 850 e-bikes and around 6,200 classic bikes, with 540 stations across the Bay Area. In San Francisco, this system had 2,813 bikes in early 2019, 250 of which were electric bicycles. In 2018, Motivate was purchased by Lyft (Lyft 2018). After this commercial acquisition, the name "Ford GoBike" changed to "Baywheels" in June 2019, and a portion of the bikes in the system were upgraded to hybrid e-bikes (Lyft 2019). The Baywheels system committed to providing equitable access to bikeshare and promised that at least 20% of bikes would be located in CoCs, as designated by the Metropolitan Transportation Commission (MTC) (Baywheels, Lyft 2019). We collected trip data from January to March 2019, thus, the following analyses retain the designation "Ford GoBike."

In addition to the dock-based system, JUMP Bike also launched a dockless e-bikeshare system in January 2018 in San Francisco, with 15 bike hubs with bike docks that have charging capabilities. Currently, there are around 1,500 electric-assisted bikes in San Francisco city. The San Francisco Municipal Transportation Agency (SFMTA) has expressed continued concerns about the management of bikes for this new system. Because of the limited number of available bikes, the system has a restricted service area. JUMP Bike will charge a user $25 if he/she drops a bike outside this service area. The system also offers a discount membership fee for just $5 during the first year, (which includes 60 minutes of daily ride time), for households identified as disadvantaged by the CalFresh program (Cal GOV 2019), PG&E, and SFMTA (JUMP 2019a) Table 3.

Even though both systems provide affordable membership plans, there are three main differences between them. First, Ford GoBike provides its plan members with a 60-minute grace period of free riding for every trip, while JUMP Bike only provides a 60-minute grace period per day, no matter how many trips were taken that day. Second, JUMP Bike charges less after the grace period than Ford GoBike. In fact, plan members from Ford GoBike can divide a longer trip into several shorter trips (less than 60 minutes) to avoid extra charges after the grace period if there are available stations along the trip. Finally, JUMP Bike allows users to enroll in their affordable plan online, but Ford GoBike only accepts in-person enrollments. Table 3 compares the characteristics of affordable membership plans for specific communities in both systems.

Table 3. Affordable membership plans provided by both systems.

System	Ford GoBike bikeshare (Dock-based) (Inc 2019)	JUMP Bike (Dockless) (JUMP 2019a)
Price	$5 annual membership ($5 month in the second year)	$5 annual membership ($5 month in the second year)
Benefit	first 60 minutes of each trip	60 minutes of ride time per day
Charge	Rides longer than 60 minutes will result in additional fees of $3 for each additional 15 minutes or potential account suspension	$.15/minute after the initial 60 minutes (or $2.25 for each additional 15 minutes). $25 Out-of-System Parking Fee
Enroll	In-person enrollment at select locations	Visit our Help Center (online) to submit a scanned copy or photo of your program documentation.
Method	No credit or debit card required	Cash payment available at selected convenience stores.
Eligibility	Bike Share for All is available to Bay Area residents ages 18 and older who qualify for CalFresh, SFMTA Lifeline Pass, or PG&E CARE.	The JUMP Boost Plan in San Francisco is available to anyone currently enrolled in one of the following programs: CalFresh, SFMTA Lifeline Pass, and PG&E CARE

Los Angeles

Another case study area selected for this research is Los Angeles County, which is comparable with San Francisco for two reasons: 1) the area is located in the same state (California), indicating consistent State-level legislation on the micro-mobility industry; and 2) during the same months studied for San Francisco, Los Angeles County also had both dock-based (Metro Bike) and dock-less (JUMP) bike-sharing systems operating concurrently. According to the Los Angeles County government website, the county has an area of 4,084 square miles and a population of nearly 10 million. The county consists of 88 incorporated cities and 2,653.5 square miles of unincorporated areas, which account for 65% of the total county area (County of Los Angeles 2016). In this research, we focused on the incorporated areas mainly covering both the docked and dockless bikeshare systems. For both systems, we selected the months of January and February 2020. Unlike San Francisco, for Los Angeles we selected 2020 data to capture the latest behavior of the systems. Additionally, we eliminated March data given that March was when the Covid-19 pandemic initially broke out in the area, which drastically changed travel behavior in the area (Los Angeles County Department of Public Health 2021). Metro Bike Share provides dock-based domain bikeshare that serves the areas of Downtown LA, North Hollywood, and Santa Monica within the county (Metro Bike 2015). It provides three different kind of bikes, including classic metro bikes, smart metro bikes, and electric metro bikes. Users need to pick up or return classis metro bikes and electric metro bikes in bikeshare stations. But, for smart metro bikes, users can lock the bikes at public bike racks within the service area for a convenience fee. This convenience fee discourages the most users from locking bikes anywhere as they want since over 80% of smart metro bike users return bikes within fixed bikeshare stations. Thus, we can still consider this system as a dock-based bikeshare system.

The bikeshare service is a result of the partnership between Metro, a multimodal transportation agency, and the city of Los Angeles. The service offers different pricing options for users. For a single ride, the system charges $ 1.75 per 30 minutes. For the membership option, the company charges $ 17/month for a monthly pass, and $150/year for a yearly pass. Users with either pass can enjoy free rides for the first 30 minutes and will get charged $1.75 per 30 minutes after the free period. The company also offers affordable payment options, shown in Table 4. The affordable plan offers a significantly lower membership fee than the standard plan, but the price is much more expensive than the affordable membership price in San Francisco.

Table 4. Affordable membership plan provided by Metro Bike (Metro Bike Share 2019).

System	Metro Bike (Dock-based)
Price	$5 per month / $50 annual membership
Benefit	All rides 30 minutes or less are free
Charge	$ 1.75 per 30 minutes after the first 30 minutes
Enroll	Email or mail application form to the designated email address/physical address
Method	Purchase from a local vendor, by phone, or on the website
Eligibility	Low-Income Fare is Easy (LIFE) provides discounted membership to low-income individuals in Los Angeles County. Adult riders, Senior/Disabled, K-12 grade students, and College/Vocational students are eligible if their incomes fall within certain limits

JUMP offered dockless bikeshare services in the area before it was sold to Lime, another micro-mobility company, in May 2020 (O'Kane 2020). The researchers were able to obtain historical data for the system from January and February in 2020, but by the time of the research, the company has closed all of its websites, making it extremely hard to get the official data of the standard, affordable pricing, and service area. However, based on our following service area analysis, JUMP Bike service is mainly concentrated in the Santa Monica area.

Bikeshare System Data

The analyses require data from both bikeshare systems. However, as would be true in cities across the U.S., the data from the two bikeshare systems in San Francisco/Los Angeles are not in the same format.

Currently, Motivate and B-cycle operate most of the dock-based bikeshare systems in the US. Among all of these dock-based systems, Motivate operates Citi Bike (New York), Divvy (Chicago), Capital Bike Share (Washington DC), Ford GoBike (Bay Area), Biki (Honolulu), and Bluebikes (Greater Boston) which together contributed over 80% of all dock-based bikeshare trips in 2018 (NACTO 2019). All of the dock-based bikeshare systems operated by Motivate and B-cycle provide trip data, including information about trip start day and time, end day and time, start station, end station, bike id, and rider type (annual member or day pass user). For the members' trips, the database also includes the riders' gender and year of birth. However, the operators do not provide information on bike availability or rebalancing activities. We also found that these limitations exist for all dock-based bikeshare systems in the US because, currently, all operators only provide trip-based data, not operational data.

On the other hand, there is no trip data for dockless bikeshare systems; companies have not shared the data in this form because of privacy concerns or commercial advantages. However, they provide information through the General Bikeshare Feed Specification (GBFS), which is an open data standard for bikeshare. The GBFS provides real-time bike information (including bike id, location, battery level, and service status), and the number of available bikes in available hubs in a city. Unfortunately, the standard does not provide the bike id when the bike is at a hub. Additionally, the real-time bike data does not include any user data. Currently, many cities have required dockless bikeshare companies (e.g., JUMP, Bird, Lime, Lyft, Skip, Spin) to share real-time data in GBFS format. If a dockless bikeshare company provides data as required, it will be information in this format and available through an application programming interface (API). We developed a web-scraping (web data extraction) tool for the systematic and continuous collection of the real-time information from GBFS (e.g., JUMP Bike). Despite its limitations, the GBFS is very useful, and we developed a robust framework based on reasonable assumptions to infer other bikeshare data (e.g., bike availability and rebalancing operations) to support our analyses.

For the study, we use historical bikeshare trip data provided by Ford GoBike; their database includes all bikeshare trips between 2013 and 2019. JUMP Bike (dockless), as mentioned, does not directly provide historical bikeshare trip data, thus, we use the web-scraping tool to gather minute-by-minute data from January to March 2019. We use this three-month sample data because, by March 2019, JUMP Bike had already been operating for over one year; thus, users were familiar with the service. Moreover, although there are some declines in bike ridership in

San Francisco at the end of the year, ridership (based on data from bike counters) does not significantly fluctuate throughout the year (T. Winters 2017). For example, during 2018 the average number of bike counts (at the available bike counters) between January and March was 15,385 per month, which is 93% of the overall monthly average of 16,533. We found similar trends when analyzing the monthly trip numbers for Ford GoBike in San Francisco. The average number of monthly dock-based bikeshare trips between January and March was 210,598 in 2019, which is 3% above the average monthly usage (204,063 trips). As these findings were an indication that the three-month sample collected was representative, the analyses compare both systems within this period (January to March of 2019).

Online Suggestion Data

The bikeshare operation companies (Baywheels in San Francisco or Metro Bike Share in Los Angeles) develop public online portals where users can suggest potential bikeshare station locations and comment on existing ones (Metro Bike Share 2021; Baywheels 2021). In this portal, users placed a dot (suggested location) on the maps of San Francisco and Los Angeles, providing a detailed description of their reasons (e.g., home, work/school, shopping, and fun) for choosing the locations, and their home zip codes (Figure 3). We applied the web scraping technology to download those suggestion data from these online portals. In San Francisco, we collected the historical information in the portal until the end of 2020. However, the data contained a number of duplicate locations by the same users and test data, which were removed. In the end, there is a total of 721 records of new bikeshare station suggestions available in San Francisco. In Los Angeles, after removing duplicated data, there are 2,354 suggestions of new bikeshare stations.

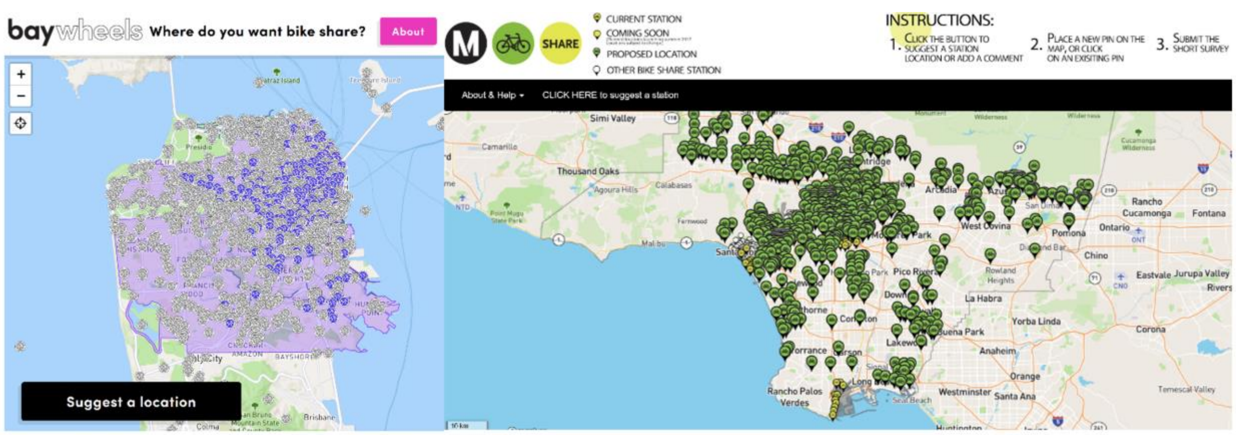

Figure 3. The screenshots of the web-based suggestion systems in San Francisco (left) and Los Angeles (right).

Methods

Analysis for Bikeshare Data

This study follows a multi-dimensional analysis to compare service levels and bikeshare activity between dock-based and dockless bikeshare systems, with a special interest in service and demand patterns at CoCs. Overall, the absence of available bikeshare stations is one of the most common barriers faced by CoCs. However, dockless bikeshare systems do not fully require physical stations (except some hubs). For the comparative analyses, we focus on service levels, including service areas, number of available bikes, bike idling time, and we calculate trip spatial distributions for both systems. We develop a set of indices that are based on these service characteristics and performance. Additionally, we consider bike rebalancing activities, which guarantee that bikes are available when needed. Together, these indices help us understand the systems' performance, measure how well/poorly CoCs are served, and identify where barriers exist and how they might be removed.

Service Areas

For the service area in CoCs, we implement different approaches to identify the number of areas and populations that dock-based and dockless bikeshare systems serve. For dock-based bikeshare systems, we create 400-meter catchment buffers for bikeshare stations (Wang and Akar 2019; Qian and Jaller 2020). The 400-meter range is selected based on the fact that people tend to walk to bikeshare stations within a quarter of a mile (Cohen 2016; García-Palomares, Gutiérrez, and Latorre 2012; Schoner and Levinson 2013). The bikeshare station will be considered as serving a census tract if a significant portion of its area is cover by the station's buffer. For dockless bikeshare, a census tract will be identified as covered as long as it falls into the service area of the dockless system. Based on the census tracts covered, we will further estimate how many census tracts are CoCs, and the covered CoCs' population.

Bike Availability, Idling, Rebalancing, and Trips

Ford GoBike and Metro Bikeshare provide matched and cleaned historical trip data, thus, trip distribution can be estimated directly from the data. Additionally, we are able to infer bike availability, idling time, and bike rebalancing by comparing the change of a bike's location and time between two continuous trips made with the same bike (Figure 4). Figure 4 Part (a) shows how we infer bike idling and bike availability, and Part (b) illustrates how we infer bike rebalancing based on bike trip data. Note that a bike is regarded as being available when it is idling. In Part (b) of Figure 4, there may be a possibility of bike idling and availability before and after a rebalancing activity (marked with * sign). However, we do not know exactly when rebalancing happens due to the data limitations, as explained. Thus, we will only count bike availability before and after the rebalance activities and ignore the bike idling time.

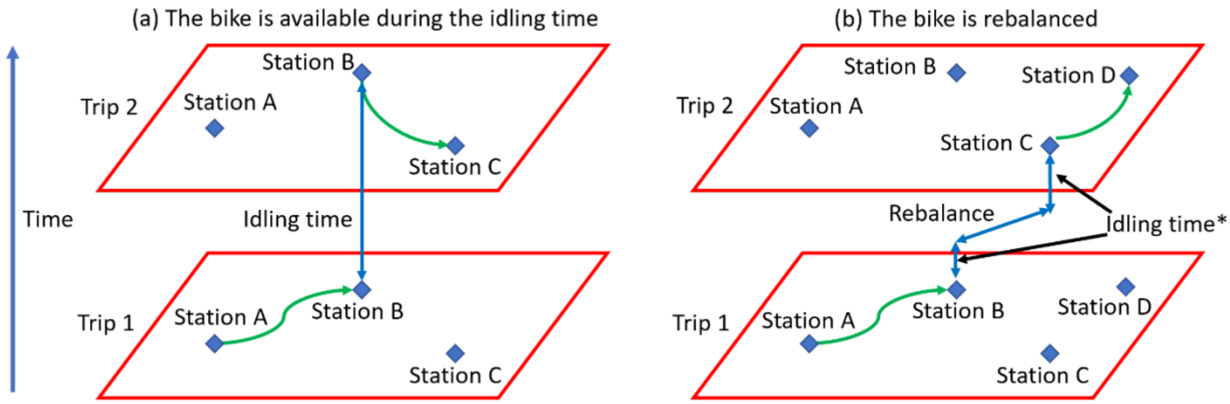

Figure 4. Calculation of bike availability, idling time and bike rebalancing for Ford GoBike (dock-based).

For JUMP Bike, bike availability and idling time can be retrieved directly from the bike status data. However, as mentioned, there are some limitations in the data, especially when the bikes are dropped at a hub or when they are rebalanced (strategically relocated and/or recharged). Consequently, calculating bike rebalances and bike trips requires a different process (Figure 5). Overall, to estimate trip origins, destinations, and durations, we use bike status changes (in-service or idle) in the scraped real-time data to determine if a bike is reserved to finish a trip, and where and when the trip starts and ends (see Figure 5).

Because bike status data does not include bikes parked in the hubs, the initial "trips" inferred by matching status changes do not necessarily include all trips generated or terminated in the hub. Considering the low density of hubs, we do not believe this unduly affects our analyses and assumptions. There are only 15 hubs in our study area, and the number of bikes moved from hubs (a trip or a rebalance; approximately 100 per day) only represents about 5.8% of the average 1,712 trips per day (JUMP 2019b). Additionally, we remove "trips" with a duration of longer than 4 hours or with an increasing battery level. After analyzing trip data, we identify those trips over 4 hours to be outliers, and they could also be those trips misrepresented by the fact that intermediate trips between hubs would not be able to be identified with the data. Specifically, a trip originating at a point A, ending at a hub, and another trip originating at the hub and ending at a point B, will be identified as a single trip between A and B, due to the limitations of the id information when bikes are dropped at a hub, and the fact that they do not show as available in the time data. The reason to exclude trips where the battery life increases is that this can only happen when system operators implement a bike battery swap and rebalance it. Therefore, an initial "trip" for the same bike id, with an increased battery level, is assumed to be a rebalancing activity.

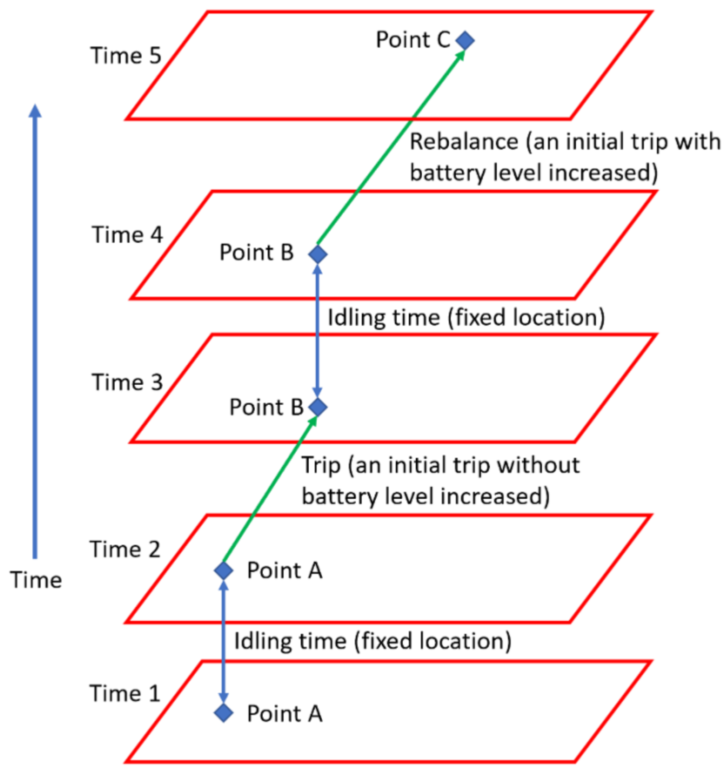

Figure 5. Calculation of bike availability, idling time, trip and bike rebalancing for JUMP Bike (dockless).

Evaluation Framework

Figure 6 summarizes the framework and assumptions used to estimate service level metrics (the number of available bikes and idling time at any given time and bike rebalancing strategies) for both dock-based and dockless systems. In addition, we aggregate the values at the census tract level for both dock-based and dockless systems and map them across all service areas.

The objective of the study is to evaluate the service levels of both bikeshare systems in terms of equity, considering the previously mentioned metrics (i.e., service areas, bike availability, bike idling, bike rebalancing, and bikeshare usage). Since dockless bikeshare systems have the advantage of no physical station restrictions, they can easily cover a broader service area (if bikes are available). Thus, we will concentrate more on the other metrics to evaluate overall service levels for CoCs.

Analysis for Online Suggestion Data

To analyze the online suggestion data, we apply spatial analyses to uncover the distribution patterns of online suggestions. The spatial analyses include two dimensions: 1) online suggestions in CoCs and non-CoCs; and 2) online suggestions and real bikeshare stations. To compare the spatial difference between the distribution of existing and suggested stations, we apply the Wasserstein metric (i.e., earth mover's distance (EMD)), which has been widely applied to compare spatial similarity (McKenzie 2020). The Wasserstein metric is a distance function to measure the difference between two probability distributions. In this study, these two probability distributions refer to the spatial distributions of the suggested locations and the existing stations. The distance can be viewed as the smallest “cost” or effort, to transform a specific station distribution into another one, like shaping one terrain into another in a sand table. The spatial analyses are conducted at the Zip-code level because this is the level of detail of the comments (though the exact location of existing and suggested locations is known). We estimate the number of suggested locations per zip code as well as for the existing station locations in San Francisco and Los Angeles. Considering that the number of suggestions is larger than the number of existing stations, we normalize both distributions and estimate the Wasserstein metric to indicate the similarity or difference.

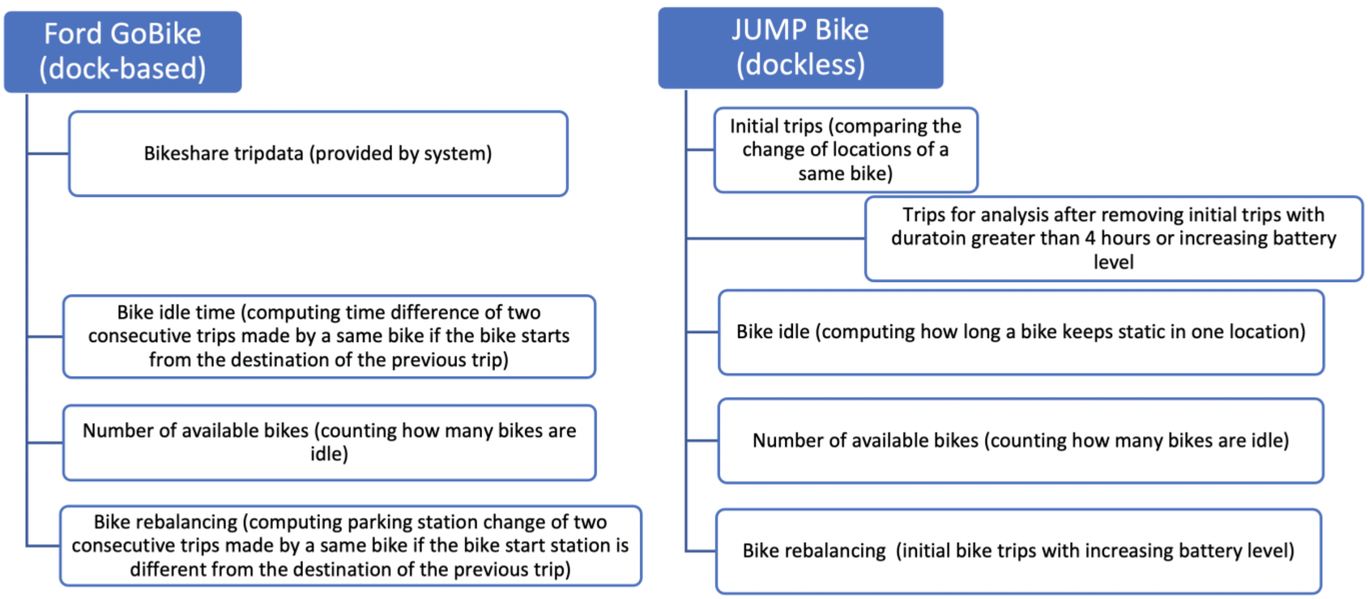

Figure 6. System data calculation methodology.

Empirical Results

Bikeshare Data Analysis

After cleaning and identifying the trip data and other attributes for both systems, we conducted the comparative analyses based on the served areas and populations with an emphasis on the spatial distribution of bike availability, bike idling, bikeshare trips, and rebalancing. The results section will present the analyses for both bikeshare trip data and online suggestion data. The analyses discuss San Francisco and Los Angeles separately.

San Francisco

Bikeshare station distribution and service area

The left panel in Figure 7 shows the distribution of bikeshare stations in the Ford GoBike system, and the blue shade is the heatmap for the density of station locations. The green boundary in the right panel in Figure 7 is the service area for JUMP Bike. However, there are bikes that are being used in census tracts outside of this service area. For example, while the service area only covers 123 census tracts in the city, the data shows the availability of bikes in as many as 190 census tracts (Table 5 and Table 6). We consider the trips in the 123 census tracts as those within the service area, while the rest are considered outside the service area.

The bikeshare stations in Ford GoBike are mainly concentrated in and around the downtown and tourist areas, while JUMP Bike has a fairly large service area. Importantly, both systems have designated restricted service areas negotiated between the companies and the local government. There is an overlap of 53 census tracts, of which 14 are high, 1 higher, and 4 highest CoCs between the service areas of the two systems. Table 5 summarizes the service area for the systems in terms of the number of census tracts, the population, and whether some of the areas are CoCs.

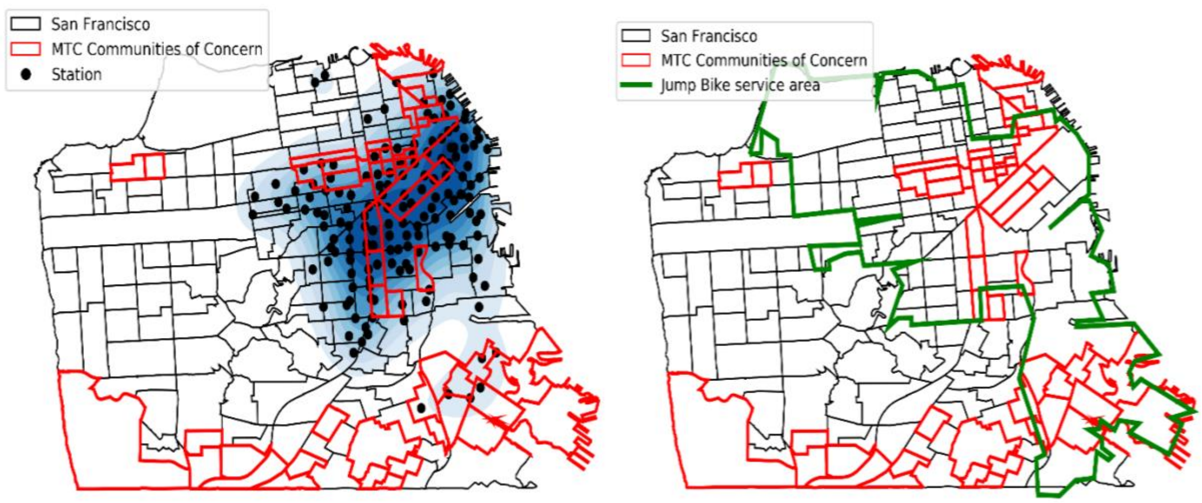

Figure 7. Service areas of Ford GoBike (dock-based, left) and JUMP Bike (dockless, right).

Bike availability and idle time

We calculate daily bike availability and how long, on average, bikes were idle in the CoCs and then compare this data to data for other non-CoC tracts. We first estimate the total number of available bikes per day across all census tracts, and then average this metric for three months for every census tract. Table 6 shows the statistics for both systems separately. Ford GoBike has a smaller number of available bikes in all CoCs (76.4 per day per tract) relative to other census tracts (98.2 per day per tract). However, based on a t-test, these two numbers do not have a significant difference (the p-value of the t-test is 0.64, which is much greater than the significance level, alpha = 0.05). In JUMP Bike, all CoCs have fewer available bikes per day (16.7) than in other non-CoC tracts (18.1) within the service area, but more available bikes per day (3.4) than in other tracts (2.3) outside the service area. We also conduct two t-tests and the p-values (0.81 for within, 0.22 for outside the service area) to show that there is not much difference in daily available bike numbers between all CoCs and other tracts in JUMP Bike. However, JUMP Bike has a greater average number of available daily bikes in CoCs at a high level than in other non-CoC tracts.

Note that the total number of bikes in JUMP Bike is around one-half of all of the bikes in the Ford GoBike system in San Francisco. Yet, JUMP Bike covers a designated service area that is approximately twice as large as Ford GoBike's service area. The average number of available daily bikes (16.7) for JUMP Bike is still approximately one-quarter of that (76.4) of Ford GoBike in the CoCs. Thus, JUMP Bike performs a little better than GoBike in terms of bike availability when serving CoCs, especially considering the small scale of its bike fleet.

Table 5. Statistics of covered areas for both systems.

System		Ford GoBike (dock-based)	JUMP Bike (dockless)
Number of tracts	Total	58	123
	All CoCs	20	36
	High CoCs	15	20
	Higher CoCs	1	2
	Highest CoCs	4	14
	Other	38	87
Population in service tracts	Total	253,701	508,335
	All CoCs	90,583	140,686
	High CoCs	69,281	84,405
	Higher CoCs	4,249	4,725
	Highest CoCs	17,053	51,556
	Other	163,118	367,649
Areas/km^2 of service tracts	Total	35.29	65.74
	All CoCs	7.95	14.99
	High CoCs	6.53	8.07
	Higher CoCs	0.44	2.60
	Highest CoCs	0.98	4.32
	Other	27.34	50.75

Note: Every CoC is also a census tract.

Table 7 shows the idling times in minutes for both systems. Before we present our results, we want to emphasize that the dock-based bikeshare data has limitations when estimating idling. We ignore the idling time for potential idling before and after a rebalancing activity (the right panel in Figure 4). For Ford GoBike, the average idling time in non-CoC tracts (372.5 minutes) tends to be longer than that found in all of the CoCs (367.2 minutes), especially for the CoCs at a high level (349.3 minutes). The statistical test shows that the difference is significant at the 90% level, with a p-value of 0.06. For JUMP Bike, the difference is more significant, especially for the CoCs at high and highest concern designations (p-value: 9.3e-83). This means that the bikes in the CoCs are used more frequently than the bikes in non-CoCs for JUMP Bike. The average bike idling time for JUMP Bike across all areas is less than that found for Ford GoBike.

This suggests that JUMP Bikes are rebalanced by system operators or used by users more frequently than Ford GoBikes.

Table 6. Statistics for daily available bike numbers per census tract.

Systems	Available bikes		Tract count	mean	min	25%	50%	75%	max
Ford GoBike (dock-based)	CoCs	All	20	76.4	1.4	17.6	40.5	87.5	429.9
		High	15	92.6	1.4	26.2	51.7	107.7	429.9
		Higher	1	3.0	--[1]	--	--	--	--
		Highest	4	34.1	12.5	17.6	30.0	46.5	64.2
	Other tracts		38	98.2	3.5	20.7	28.9	58.8	839.4
JUMP Bike (dockless)	CoCs	All	36/14[2]	16.7/3.4	1.1/1.0	3.4/1.0	7.6/1.3	15.2/3.7	112.4/21.1
		High	20/11	23.1/4.0	1.1/1.0	4.7/1.1	10.8/1.3	29.3/4.3	112.4/21.1
		Higher	2/1	4.5/1.8	3.0/--	--/--	--/--	--/--	5.9/--
		Highest	14/2	9.2/1.0	1.7/1.0	3.6/--	5.1/--	10.7/--	42.9/1.0
	Other tracts		87/53	18.1/2.3	1.0/1.0	5.0/1.4	10.0/1.6	18.6/2.1	243.3/13.8

Note 1. "--": there is only one tract in this category;
2. the left number is for the tracts within the service area while the right one is outside the service area.

Table 7. Statistics for bike idle time (minute) on average.

Systems	Bike idle time/minute		Bike count	mean	min	25%	50%	75%	max
Ford GoBike (dock-based)	CoCs	All	130813	367.2	0.12	17.2	70.1	413.1	52,964.2
		High	119,011	349.3	0.12	16.3	65.8	380.5	52,964.2
		Higher	181	2,810.5	2.19	539.1	1,208.0	2,600.0	52,125.3
		Highest	11,621	512.9	0.16	31.4	142.3	593.9	22,705.4
	Other tracts		295,283	372.5	0.06	17.0	80.5	465.1	103,715.7
JUMP Bike (dockless)	CoCs	All	53,107/2,731[1]	120.2/162.9	0.5/0.5	3.3/4.0	21.1/29.1	84.1/115.0	15.6d[3]/15.5d
		High	41,422/2,692	106.5/155.6	0.5/0.5	4.0/4.0	21.2/28.4	80.2/111.3	15.6d/15.5d
		Higher	563/37	710.9/684.1	0.5/0.5	0.5/74.3	66.1/277.0	867.9/853.2	10.4d/2.6d
		Highest	11,122/2	141.4/279.0	0.5/4.0	2.2/--[2]	20.4/--	97.0/--	11.0d/0.38d
	Other tracts		140,774/4,639	163.4/263.4	0.27/0.5	4.9/2.0	31.5/37.5	138.0/243.2	24.7d/12.3d

Note 1. the left number is for the tracts within the service area while the right one is outside the service area;
2. "--": there is only two data point in this category;
3. the unit is a day (d) instead of a minute to be concise.

Bikeshare rebalancing

Bikeshare rebalancing occurs in both systems. For Ford GoBike, bikes are more likely to be rebalanced from the central areas moving to the periphery of the service area (Figure 8). Most of the rebalancing activities are within non-CoC tracts (Table 8). The proportion of rebalancing within the CoCs is only 5.1% (1,956/37,987), disproportionate to the service areas covered by the Ford GoBike system (areas: 7.95/35.29 = 23%; tracts:20/58 = 34%). Interestingly, comparing rebalancing between CoCs and non-CoC tracts, the number of bikes moved from non-CoC tracts to the CoCs is 50% more than the number moved from the CoCs to non-CoC tracts, which means that more bikeshare trips flowed into non-CoCs from CoCs during our study period (3 months).

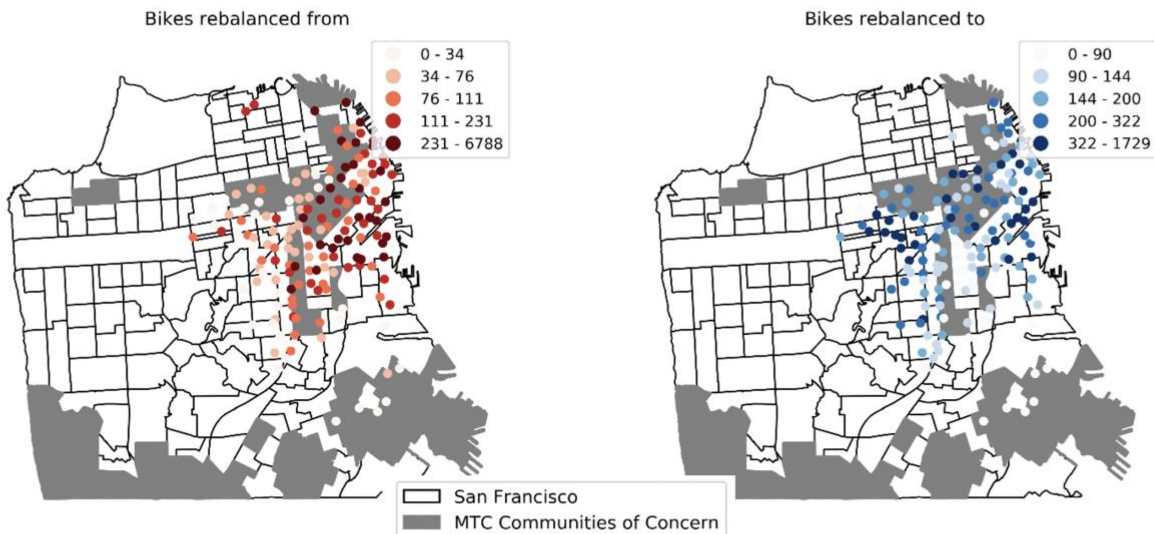

Figure 8. Distribution of bike rebalancing origins and destinations in Ford GoBike (dock-based).

Table 8. Rebalance classification.

Systems	Ford GoBike (dock-based)	JUMP Bike (dockless)
Within CoCs	1,956 (5.1%)	2,775 (11.0%)
From CoCs to non-CoCs	4,438 (11.7%)	4,117 (16.3%)
From non-CoCs to CoCs	6,641 (17.5%)	3,887 (15.4%)
Within non-CoCs	24,952 (65.7%)	14,445 (57.3%)
Total	37,987	25,224

For JUMP Bike, we mentioned that information about bikes in the hubs is not available. However, because of the small portion of trips starting from the hubs (less than 6%), it is reasonable to omit those trips from the analyses. Therefore, we can consider all bikeshare trips where the battery level increases as rebalancing activities. Under this assumption, we plot the kernel density estimation of bike rebalancing activities (Figure 9). Both rebalancing origins and destinations occur near the financial district in San Francisco. After dividing the rebalancing activities into four categories, as done for the Ford GoBike (Table 8), we can see that the proportion of bike rebalancing activities in the CoCs for JUMP Bike (11.0%) is higher than for Ford GoBike (5.1%). The number of rebalancing activities within the CoCs (2,775) is also greater than that (1,956) of Ford GoBike. This supports our earlier observations about bike availability and idle time in the CoCs.

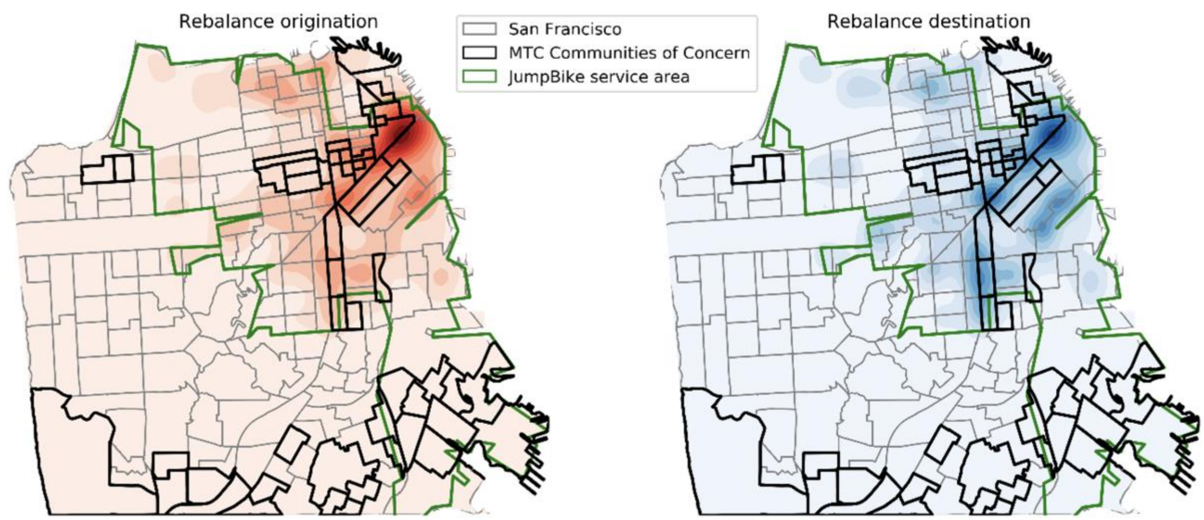

Figure 9. Kernel density estimation of the distribution of bike rebalancing origins and destinations in JUMP Bike (dockless).

Bikeshare ridership

Trip distribution is an important feature to measure bikeshare coverage of CoCs and how users from CoCs utilize the service. For both systems, the areas with larger trip generation are also where users are most likely to end their trips (Figure 10 and Figure 11). Most of the bikeshare activities happen near the city's downtown area (northeast), where there are also many CoCs. Note that the CoCs in the northwest and southeast of San Francisco, where there are a few bikeshare stations and almost zero trips from Ford GoBike, can be covered by JUMP Bike service. Table 9 shows that the absolute value of the bikeshare trip generated in the CoCs by JUMP Bike is smaller than that by Ford GoBike. However, from the perspective of the ratio between the CoCs and non-CoCs, JUMP Bike has almost the same proportion of trips in the CoCs (38.3%/38.2%) within the designated service area as Ford GoBike (42.9%/42.0%). For the trips from/to the tracts outside the service area, more than half (58.9%/58.5%) of the trips are within the CoCs at a high level, which is double the proportion (29.8%/29.5%) of those in the service area in JUMP Bike.

Table 9. Statistics for bike trip numbers.

System	Tract types	Trip origins	Ratio to other tracts	Trip destinations	Ratio to other tracts
Ford GoBike (dock-based)	All CoCs	139,896	42.9%	137,797	42.0%
	High CoCs	127,260	39.0%	125,212	38.2%
	Higher CoCs	213	0.06%	238	0.07%
	Highest CoCs	12,423	3.8%	12,347	3.8%
	Other tracts	326,073	100%	328,172	100%
JUMP Bike (dockless)	All CoCs	44,855/2,128[1]	38.3%/59.4%	44,620/2,316	38.2%/59.1%
	High CoCs	34,900/2,109	29.8%/58.9%	34,493/2,291	29.5%/58.5%
	Higher CoCs	484/18	0.4%/0.5%	464/24	0.4%/0.6%
	Highest CoCs	9,471/1	8.0%/0.0%	9,663/1	8.3%/0.0%
	Other tracts	117,076/3,580	100%/100%	116,787/3,917	100%/100%

Note 1. the left number is for the tracts within the service area while the right one is outside the service area.

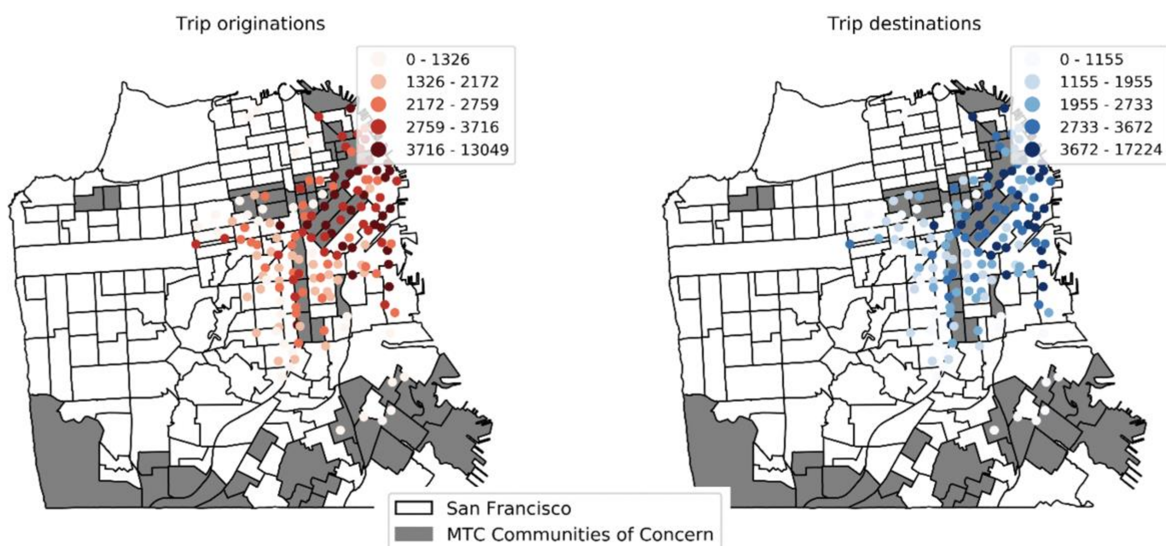

Figure 10. Distribution of trip origins and destination in Ford GoBike (dock-based).

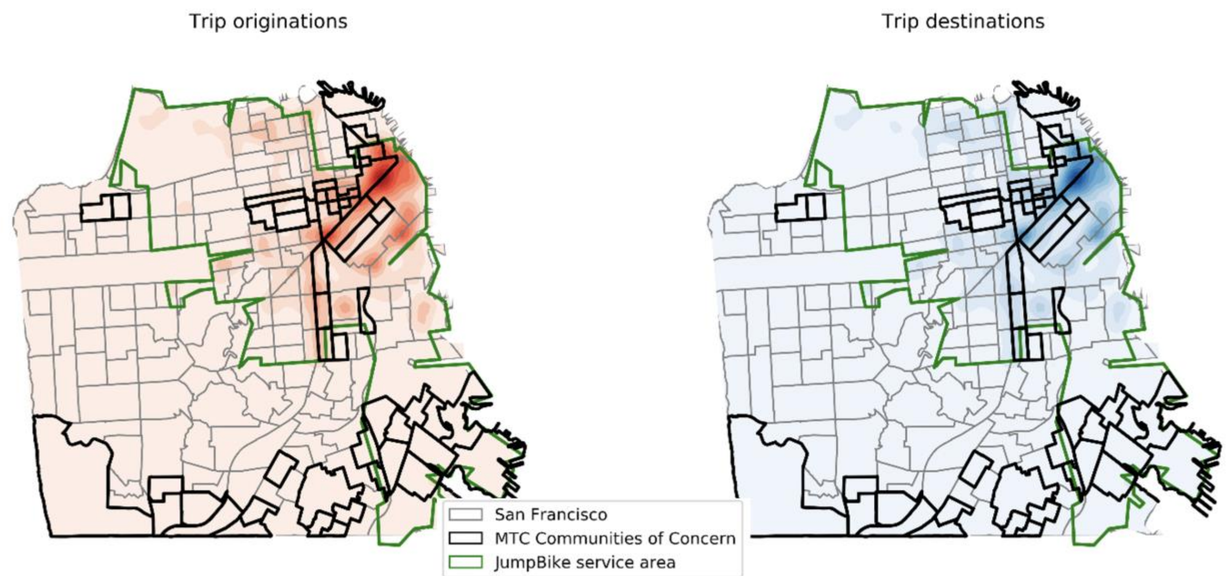

Figure 11. Kernel density estimation of the distribution of trip origins and destinations in JUMP Bike (dockless).

Table 10 shows the statistics of trip time for bikeshare trips in both systems. We divide all OD pairs into four categories: 1) within CoCs; 2) from CoCs to non-CoCs; 3) from non-CoCs to CoCs; 4) within non-CoCs. In Ford GoBike, the average trip times among different OD types are similar. When we observe the trip time features of JUMP Bike, trip times between the CoCs and non-CoCs (1,986/2,016) are significantly larger than those of trips within non-CoCs (1,560). Overall, the average bikeshare trip time in JUMP Bike is significantly greater than that of trips in Ford GoBike. Considering the broadened trip distribution area, we infer that as JUMP Bike covers more areas, including both CoCs and other areas, users may use dockless bikeshare services to finish trips that may have previously been made using other modes. The reader is referred to Campbell and Brakewood (2017) and Oeschger et al. (2020) for recent studies about micromobility mode substitution and transit connectivity.

Since San Francisco is a hilly city, electric bikes may be more attractive to bikeshare users than traditional bikes. Some CoCs (e.g., Chinatown) have particularly hilly terrains. We further examine the influence of elevation on bikeshare usage for both systems. As the numbers of trip origins and destinations are almost the same for a single census tract (Table 9), we only pay attention to trip origins. As we can see in Figure 12, higher elevation will reduce bikeshare usage regardless of whether in dock-based or dockless systems. However, JUMP Bike has more usage than Ford GoBike in areas with high elevations.

Table 10. Statistics for trip time (seconds) for Ford GoBike (dock-based) and JUMP Bike (dockless).

System	OD type	mean	min	25%	50%	75%	max
Ford GoBike (dock-based)	1	680	61	288	467	749	14,173
	2	748	61	399	589	864	14,272
	3	745	62	409	608	869	14,235
	4	747	61	349	566	881	14,375
JUMP Bike (dockless)	1	1,200	59	121	569	1,439	14,374
	2	1,986	60	847	1,319	2,158	14,397
	3	2,016	59	853	1,326	2,187	14,399
	4	1,560	13	240	1,013	1,906	14,399

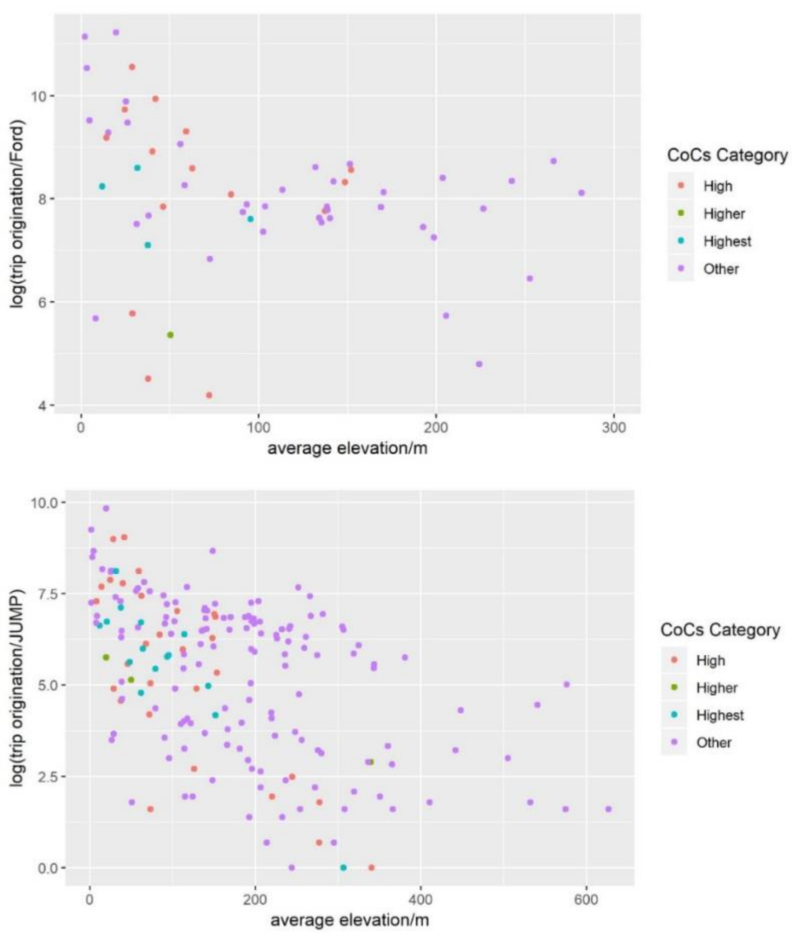

Figure 12. Trip origin per census tract against average elevation.

To understand if the influence of elevation could be affected by area categories (CoCs or not), we conduct a negative binomial regression as suggested by Qian and Jaller (2020). The results are shown in Table 11. The fact that elevation has a negative effect on bikeshare ridership is illustrated by Figure 12. However, the magnitude of this effect is smaller for JUMP Bike. Besides, the CoC categories (High/Higher/Highest) play a less important role in determining JUMP Bike usage than Ford GoBike usage, no matter the significance levels or the coefficient values. This may be explained by the fact that all bikes in JUMP Bike are electric. Nevertheless, a further survey study may be needed to verify if users from CoCs prefer e-bikes to traditional bikes since e-bikes can provide greater accessibility in a hilly city.

Table 11. Annual bikeshare ridership estimation models for trip origins.

Variables	Ford GoBike (dock-based)		JUMP Bike (dockless)	
	Coefficient	Significanc	Coefficient	Significance
Constant	9.5421	***	7.6008	***
Average elevation	-0.0092	***	-0.0083	***
CoC: Higher	-3.7199	***	-1.8711	*
CoC: Highest	-1.1273	.	-0.7178	.
CoC: Other	0.2561		0.3519	
Log-likelihood	-560		-1343	
AIC	1131		2698	

Los Angeles

Bikeshare station distribution and service area

The spatial difference between the two bikeshare systems is presented in Figure 13. The visualization shows drastically different representations of service areas between dock-based and dockless bikeshare systems. For the dock-based bikeshare system, Metro Bike, the service area is generated according to the locations of the bike stations. Due to the nature of the dock-based operation, the bikeshare service is not likely to reach communities far away from the bike stations. According to the left figure, there are three major clusters of bike stations: downtown Los Angeles, Santa Monica, and North Hollywood. Among the three clusters, downtown Los Angeles shows the highest concentration of bike stations.

By comparison, the service area for the JUMP bike shows a different pattern. In the right figure, the service area is the area enclosed by the green boundary. The team generated this area based on the distributions of the bike idling activities of JUMP. There are two reasons for this approach. The first is the loss of official definition. After JUMP closed in 2020, the company's website was also closed. Therefore, getting an official definition of the service area proved to be extremely difficult. The second reason is the operation method of JUMP. Unlike Metro Bike, the dockless bikeshare service of JUMP allows for parking a bike outside the service area with a 20-dollar penalty. However, the real permitted service area of JUMP Bike should be much smaller than the one shown in Figure 13. Based on the following bike idling analysis (Figure 14 and Figure 15), the real service area should be concentrated in Santa Monica, which is to the west of Los Angeles. Note that this fact may lead to inconsistencies in the analysis results for Los Angeles, which will be explained more later.

From the data visualization, both systems show some degree of coverage of CoC areas and non-CoC areas. To better understand the service area, summary Table 12 is generated below, showing that JUMP bike has a larger service area for both CoC areas and non-CoC areas.

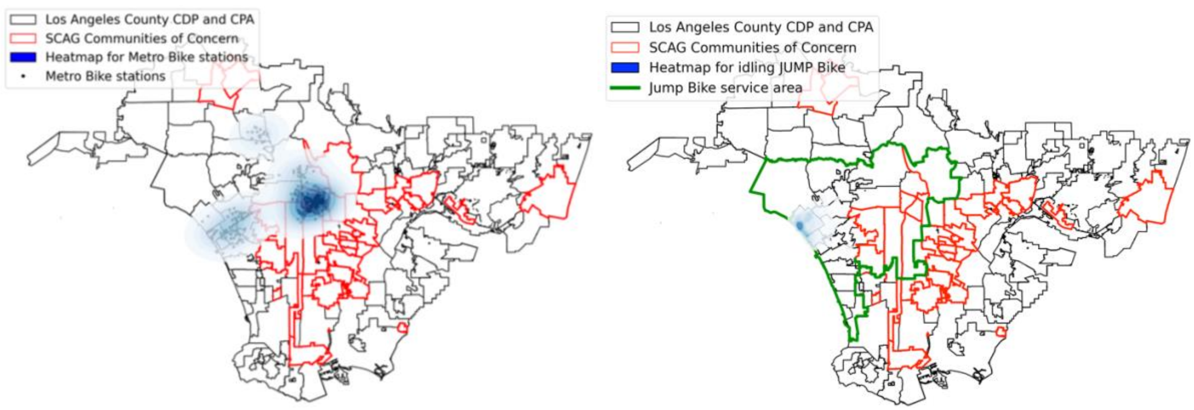

Figure 13. Service area of Metro Bike (left) and JUMP (right).

Table 12. Statistics of service areas for both systems.

System		Metro Bike Share (dock-based)	JUMP Bike (dockless)
Number of CDP and CPA	Total	16	26
	CoCs	4	7
	Other	12	19
Areas/km^2 of service tracts	Total	571.60	939.61
	CoCs	139.97	314.46
	Other	431.63	625.15

Bike availability and idle time

The bike idlings of the two systems are compared in two metrics: the daily number of bikes per track and idling durations (Table 13 and Table 14). Metro Bike has similar average daily bike numbers per tract. Across the four CoC tracts covered by Metro Bike, the number of available bikes does not vary too much, compared to available bike numbers in non-CoC tracts. One possible reason why the non-CoC tracts have greater variation is that some of the non-CoC tracts have a very limited number of Metro Bike stations that are also not actively used, as the company has closed some of its stations since February of 2020. Despite the difference in available bike numbers, the idling duration of Metro Bike showed similarity between CoC tracts and non-CoC tracts. JUMP bikes, by comparison, showed a different pattern in terms of available bikes. All of the CoC tracts within the JUMP service area had a significantly smaller number of available bikes than non-CoC tracts. The difference among the CoC tracts is smaller than the difference among the non-CoC tracts. Comparing the two systems, Metro Bike has a more homogeneous distribution in daily available bike numbers among CoC tracts and non-CoC tracts. In terms of idling durations, JUMP bikes generally have less idling duration than Metro Bike. The spatial visualizations of the bike idling for the two systems are presented in Figure 14 and Figure 15. From the figures, we can observe that most of the bike idling activities for Metro Bike are located in downtown Los Angeles, while JUMP has most of its bike idling distributed along the coast and highly concentrated in the Santa Monica area.

Table 13. Statistics for daily available bike numbers per Los Angeles CDP and CPA track.

Systems	CoC	Tract count	mean	min	25%	50%	75%	max
Metro Bike (dock-based)	CoCs	4	53.9	17.5	40.1	54.0	67.7	89.6
	Other tracts	12	51.1	0.5	2.6	13.9	29.3	440.7
JUMP Bike (dockless)	CoCs	7	1.31	< 0.1	0.48	1.04	1.55	4.02
	Other	19	129.21	< 0.1	0.45	2.72	39.32	1709.37

Table 14. Statistics for bike idle time (minute) on average.

Systems	CoC Status	Bike count	mean	min	25%	50%	75%	max
Metro Bike (dock-based)	CoCs	12,699	1478.4	< 1.0	4.0	189.0	1081.0	76,576.0
	Other	36,144	1,320.7	< 1.0	11.0	160.0	1044.0	73,301.0
JUMP Bike (dockless)	CoCs	422	462.2	< 1.0	9.0	96.0	604.5	7,981.0
	Other	112,931	375.1	< 1.0	6.0	62.0	417.0	49,008.0

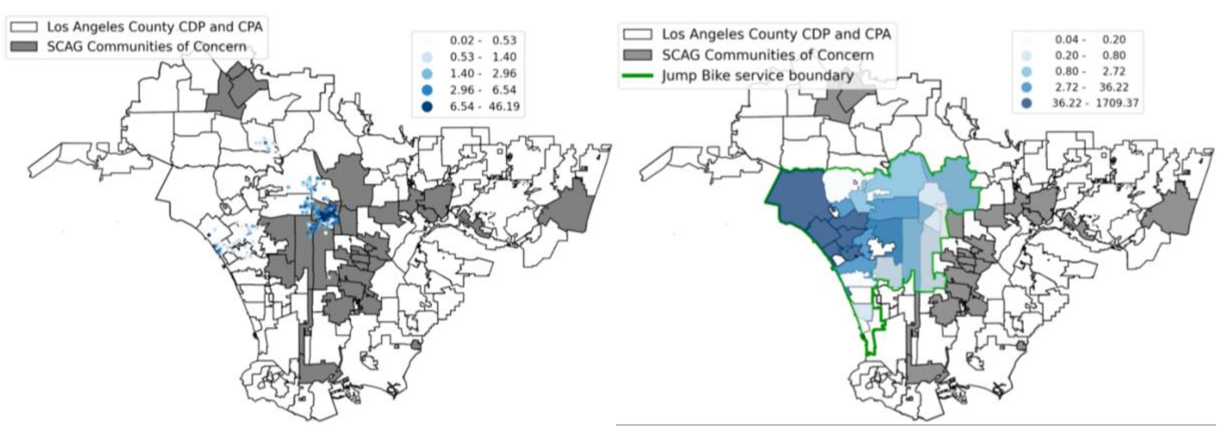

Figure 14. Number of daily available bikes of Metro Bike (left) and JUMP (right).

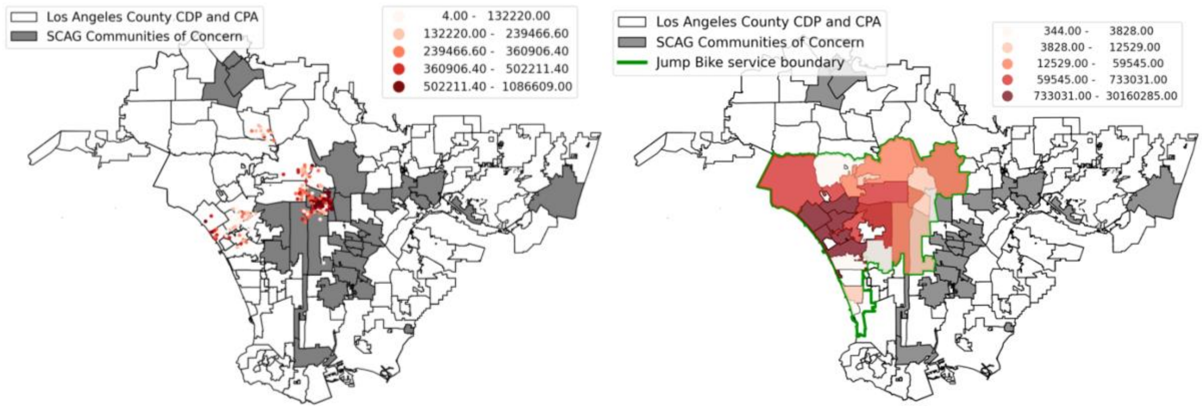

Figure 15. Total idling duration (minutes) of Metro Bike (left) and JUMP (right).

Bikeshare rebalancing

The rebalancing activities between CoC tracts and non-CoC tracts are summarized in the table below (Table 15). For both dock-based and dock-less bikeshare systems, the total number of activities is similar for both systems, with the rebalancing activities within the CoC tracts being the least active. However, one notable discovery is that the dock-based bikeshare system (Metro Bike) has more similar activity across CoC tacks and non-CoC tracts, contrasting with the dockless bikeshare system (JUMP), where most activities occur within non-CoC tracts. The visualizations of the rebalancing activities are also shown in Figure 16 and Figure 17. The difference between the two systems is clear. Most of the rebalancing activities for the dock-based system are concentrated in the Los Angeles downtown areas, while more activities are distributed in the Santa Monica beach area for the dockless system. This result aligns with the findings for bike idling, which is consistent with the demand patterns across the areas in the city.

Table 15. Rebalance Classification.

Systems	Metro Bike (dock-based)	JUMP Bike (dockless)
Within CoCs	350	15
From CoCs to non-CoCs	1,421	57
From non-CoCs to CoCs	1,045	41
Within non-CoCs	2,733	5944
Total	5,550 (100%)	6057 (100%)

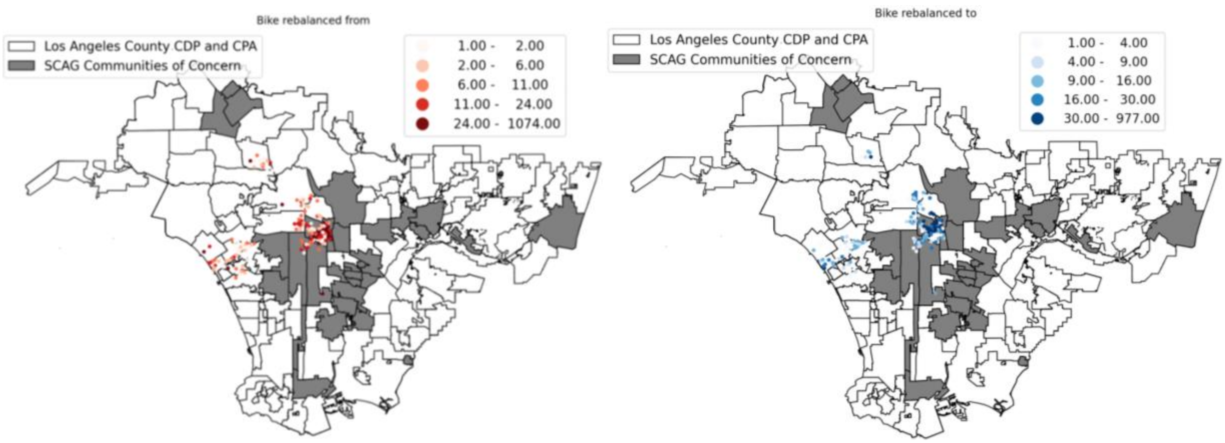

Figure 16. Distribution of bike rebalancing origins and destinations in Metro Bike (dock-based).

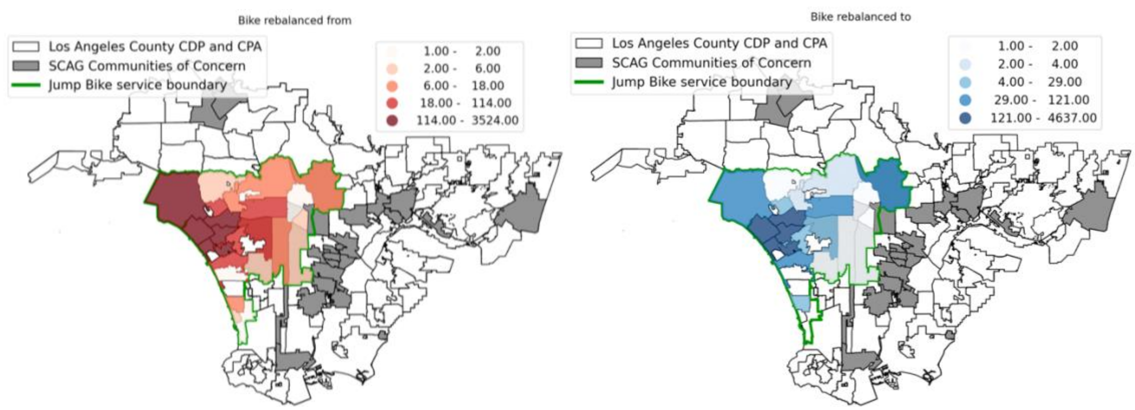

Figure 17. Distribution of bike rebalancing origins and destinations in JUMP (dock-less).

Bikeshare ridership

The statistics of bikeshare trips are summarized in Table 16. According to the table, within the same system, there is no significant difference between the numbers of trip origin and destination. In both systems, more trips were originated or ended in non-CoCs, which is more significant in the dockless system. For the dock-based Metro Bike, the proportion of trips in CoCs (36%/38%) is greater than the ratio of CoC areas covered by its system (24%), while JUMP has disproportionally more trips in non-CoCs than in CoCs. The dockless JUMP bike, by contrast, is extremely inactive in CoC areas, which is mainly caused by its restricted service area, i.e., the Santa Monica region. This can be verified by the rebalancing activities in JUMP Bike, as shown in Figure 17. Users will also be charged 20 dollars for parking a bike outside the service area.

Table 16. Statistics for bike trip numbers.

System	Tract types	Trip origins	Ratio to other	Trip destinations	Ratio to other tracts
Metro Bike (dock-based)	CoCs	14,296	36.0%	14,878	38.0%
	Other tracts	39,760	100%	39,178	100%
JUMP Bike (dockless)	CoCs	328	0.3%	372	0.3%
	Other tracts	111,168	100%	111,124	100%

Table 17 summarized the trip durations of both systems across the four different origin-destination types, which is the same approach we use in San Francisco. From the table, we see that the mean travel time in JUMP is greater than that in Metro Bike Share across all OD types. One reason for this is that JUMP Bike provides electric bicycles, which are more comfortable for riders than manpower bicycles on the coast of Santa Monica. Another reason is that a 5-minute travel time threshold is set when we processed the dockless bike data in Los Angeles. Based on our observation, the Los Angeles data for JUMP Bike has more noise than their data in San Francisco. Figure 18 and Figure 19 show the spatial distribution of bikeshare trip durations. It is clear that JUMP Bike is more active in the San Monica region and the duration is much greater there since users may mainly make bikeshare trips for recreational purposes.

Table 17. Statistics for trip time (seconds) for Metro Bike (dock-based) and JUMP Bike (dock-less).

System	OD type	mean	min	25%	50%	75%	max
Metro Bike (dock-based)	1	949	60	300	600	1080	14400
	2	847	60	420	660	1020	14340
	3	825	120	420	660	1020	13860
	4	975	60	300	600	1140	14400
JUMP Bike (dockless)	1	1078	301	421	660	1410	14219
	2	1233	301	391	600	1140	14219
	3	898	301	464	660	1020	3899
	4	1190	301	420	659	1080	14400

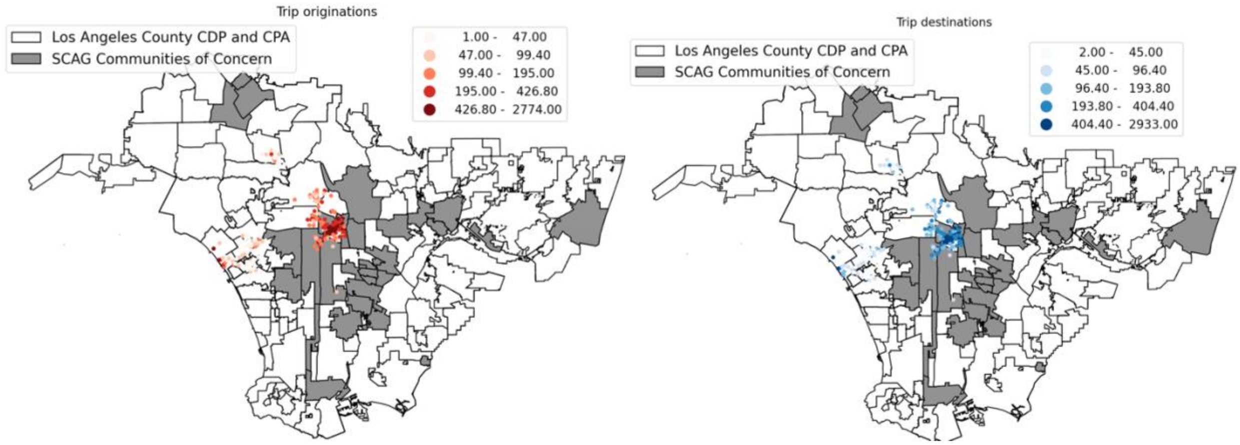

Figure 18. Distribution of bike trips origins and destinations in Metro Bike (dock-based).

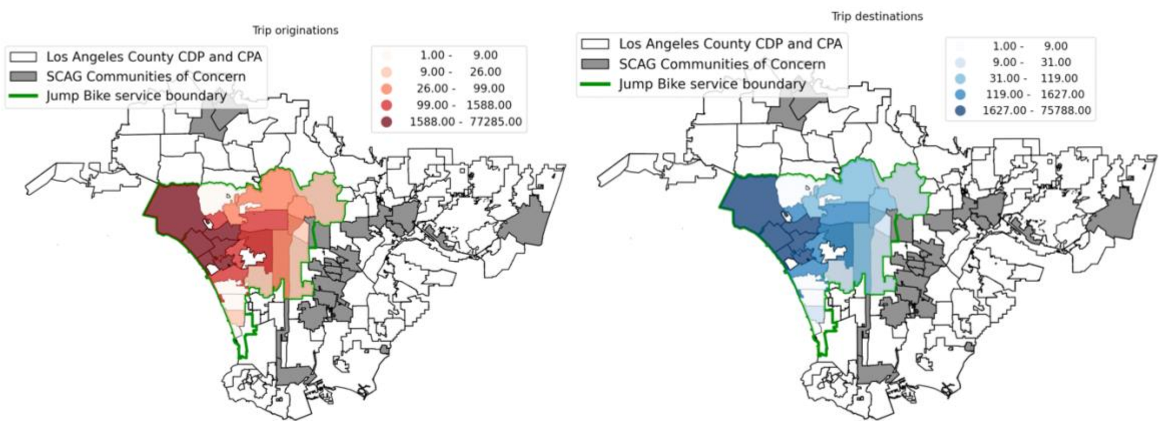

Figure 19. Distribution of bike trips origins and destinations in JUMP (dock-less).

Online Suggestion Data Analysis

As mentioned, the dock-based bikeshare systems in both San Francisco and Los Angeles provide online portals where users can suggest locations for future stations based on their needs. Previous research has studied the potential application of this crowdsourced online suggestion data for bikeshare station planning (Griffin and Jiao 2019b). In this section, we analyzed the spatial distribution of the suggestions, and performed a spatial similarity analysis between actual bikeshare station siting and suggested station distribution to gain insights on how bikeshare systems can serve the CoCs compared to other regions. In the following sections, we will present the results in the two cities separately.

San Francisco

shows a spatial distribution of the suggested stations in San Francisco. By comparing the spatial distribution (mainly concentrated in the downtown) of current stations in Figure 7, the suggested stations are more evenly scattered with four major clusters across the city. By plotting the suggested stations within CoC tracts and outside of CoC tracts (Figure 21), we observe that the suggestions within CoC tracts are mainly located on the east side of the city, while suggestions located outside of CoC tracts are more evenly distributed.

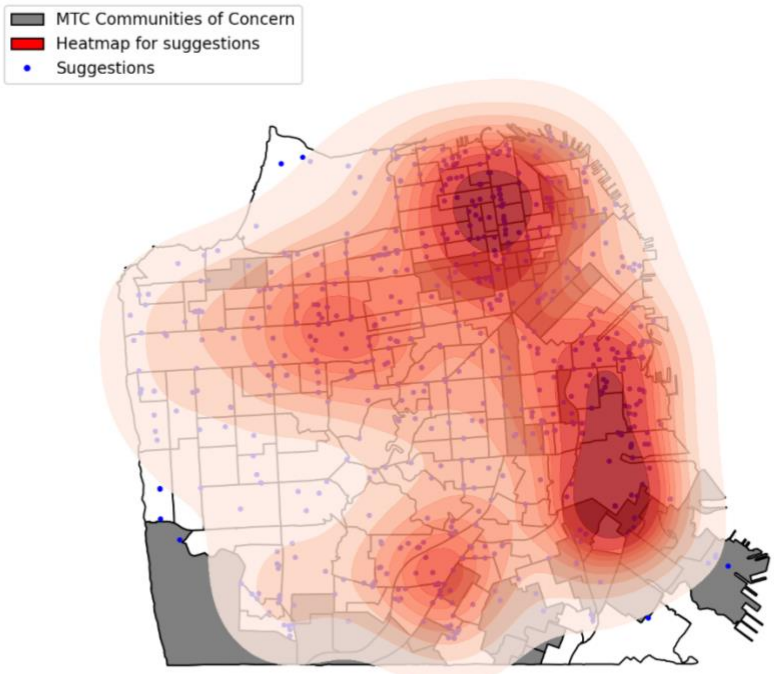

Figure 20. Heatmap for the suggestions in San Francisco.

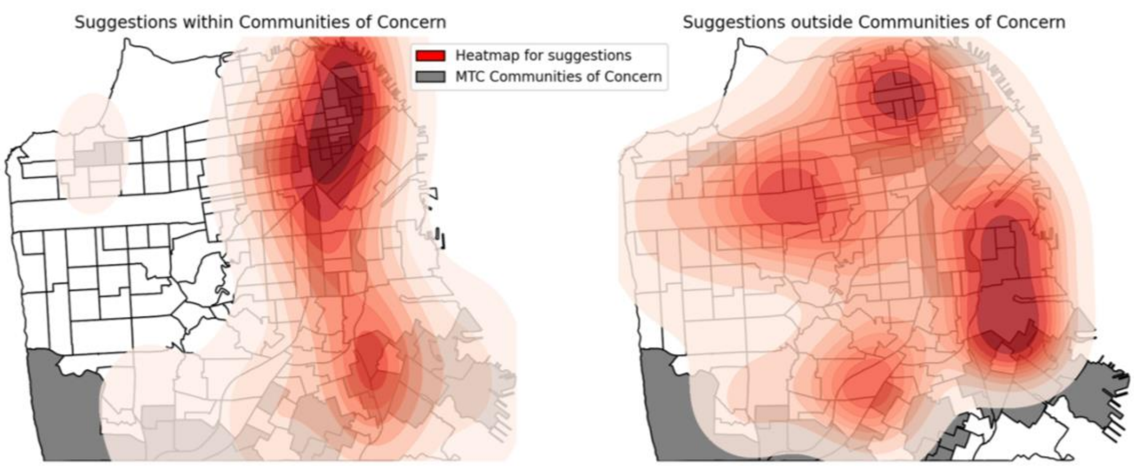

Figure 21. Comparison of the suggestions within CoC and outside CoC.

We generated a summary table (Table 18) to examine the difference between the current stations and the suggested stations in all CoC levels. For both the current and suggested stations, more than half of the station/suggestion counts are located in non-CoC tracts. Regarding the stations/suggestions per one thousand people in different tracts, the number in CoCs for the current stations is slightly larger than that in non-CoC tracts. By comparison, the non-CoC tracts have more suggested stations per thousand people than CoC tracts. The reason for the difference may be that the participants from CoCs are much fewer than those from non-CoCs. The reason for the lower participation in CoCs may be the missing of incentive programs since the incentive may be more attractive for residents in CoCs than those living in Non-CoCs. It is also noticeable that the biggest difference between current stations and the suggestions is in the Higher CoC tracts. Currently, there are 0.014 bike stations for every one thousand people living in Higher CoC tracts, the least of all tracts. But for suggested stations, there are 0.77 stations per thousand people in the tract, the largest increase among all CoC tracts.

Table 18. Number of suggestions in different CoC Levels.

	CoC Levels	Current Stations	Suggested Stations
Stations count tracts	High	38 (23.60%)	81 (11.23%)
	Higher	2 (1.24%)	9 (1.25%)
	Highest	9 (5.59%)	18 (2.50%)
	NA	112 (69.57%)	613 (85.02%)
	Total	161 (100%)	721 (100%)
Stations per 1,000 people	High	0.27	0.57
	Higher	0.014	0.77
	Highest	0.15	0.31
	NA	0.18	0.97
	Total	0.19	0.85

In its web-based suggestion system, the bikeshare company allows users to input the main trip purposes for each suggestion. In the online portal, the user can choose one or more of the following categories as the purpose: work/school, shopping, fun, and home. We collected this data and summarized the number of trip purposes in Table 19. In all CoC tracts, a significantly large proportion of the suggestions are designated to work/school (87.96%), indicating that the people in CoC tracts use the bikeshare service primarily to go to work or attend schools. On the contrary, the top purposes in non-CoC tracts are Work/School (69.33%) and Fun (65.42%), which reveals that the people in non-CoC tracts tend to use bikeshare for entertainment purpose in addition to Work/School.

Table 19. Statistics for suggestions across purpose and area types.

Tract types	Work/School	Shopping	Fun	Home	Total
All CoCs	95 (87.96%)	44 (40.74%)	65 (60.19%)	69 (63.89%)	108
High CoCs	74 (91.36%)	36 (44.44%)	51 (62.96%)	52 (64.20%)	81
Higher CoCs	8 (88.89%)	2 (22.22%)	5 (55.56%)	5 (55.56%)	9
Highest CoCs	13 (72.22%)	6 (33.33%)	9 (50%)	12 (66.67%)	18
Other tracts	425 (69.33%)	245 (39.97%)	401 (65.42%)	284 (46.33%)	613

In Figure 22, we plotted the distributions of all suggestions for each purpose. It can be observed that the distribution of the purposes of home, work/school, and shopping share a similar pattern: the downtown area (top right corner of the city) has the largest concentration of the suggestions, while the south of the city has a small peak of suggestion concentration. The suggestions with the purpose of fun, however, are densely located in the lower right corner of the city. This observation suggested that this lower right corner of the city might have been an area of entertainment for the local community. Traditionally, we would expect that the main attractions of entertainment are located in the downtown area or other places with tourist destinations. Although those areas have a huge demand for bikeshare stations, they are usually the places that already have extensive coverage of bike stations. This visualization for San Francisco has revealed that some of the alternative areas might also have a huge demand for bike stations for entertainment purposes. To further study the demand for bikeshare stations, a greater understanding of the area on a community level is needed.

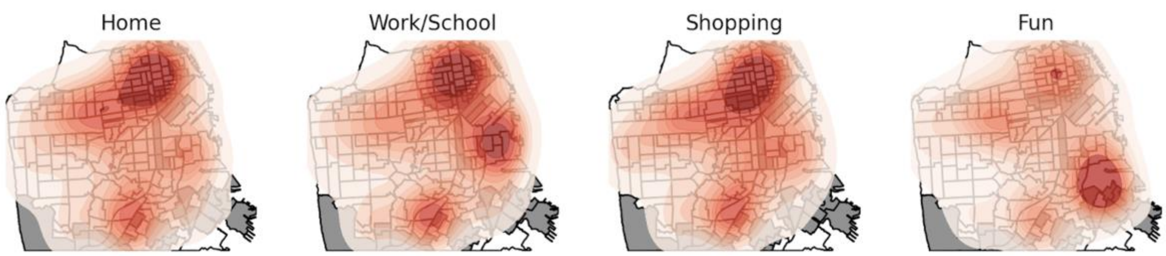

Figure 22. Comparison of heat map between suggestions within CoC and Suggestions outside CoC.

In addition to the summary statistics and spatial visualizations, we also performed a spatial similarity analysis between the suggested data and the current stations across all purpose levels by calculating the Wasserstein metric value (Table 20).

After calculating the metric value, we also obtained the relative value of each purpose compared to all purposes. The smaller the relative value, the more similar the distribution of the suggested stations is with the current stations. We see that for suggestions from all tracts, the demands for work/school and fun match the current station distribution the most. A similar trend can also be found for the suggestions within non-CoC tracts. The suggestions within CoC tracts, in contrast, showed that the demand for shopping is closest to the current distribution of stations. By comparing Table 20 with Table 19, we can infer whether the distribution of bike stations can serve the demand of people from disadvantaged areas and non-disadvantaged areas. Recall in Table 19, work/school and fun are the most popular purposes with a similar proportion (69.33% and 65.42%) of the total suggestions in non-CoCs. The small relative Wasserstein metric value in non-CoC tracts implied that the current stations served the most demanded trips (work/school and fun) well in these areas. While the disadvantaged area (CoC tracts) showed that the most significant demand is for work/school (87.96%) in Table 19, Table 20 showed the demand is not well addressed by the current bike services, with the distribution of suggested stations for shopping purpose being the most similar to the current bike station distribution.

Table 20. The spatial similarity between suggested and actual stations siting in San Francisco.

Station	Purposes	Wasserstein metric value	Relative value
All suggestions	All purposes	2.50	1.00
	Home	3.10	1.24
	Work/School	2.58	1.03
	Shopping	3.07	1.22
	Fun	2.71	1.08
Suggestions within CoCs	All purposes	1.24	1.00
	Home	1.47	1.18
	Work/School	1.26	1.02
	Shopping	1.21	0.97
	Fun	1.36	1.09
Suggestions outside of CoCs	All purposes	2.82	1.00
	Home	3.61	1.28
	Work/School	2.99	1.06
	Shopping	3.46	1.23
	Fun	3.01	1.07

Note: the relative value under each Station category is calculated by dividing the Wasserstein metric value of each purpose by the value of "All purposes".

Los Angeles

In the previous section, we analyzed the distribution of the current stations in the Los Angeles metro area and found three major clusters of stations. Figure 23 showed a different distribution of the suggested stations in the area. The suggested stations are more widely distributed in the area, showing that the demand for bikeshare stations is great throughout the area. Among all suggestions, two areas show exceptional demand for stations (two hotspots in the map): downtown Los Angeles (right hotspot) and the area connecting downtown with the City of Santa Monica (left hotspot). Figure 24 shows the distribution comparison of the suggestions within CoCs and the suggestions outside of CoCs. The two types of communities show a drastically different demand for stations. The suggestions within the CoCs are more centered within the downtown Los Angeles area, while the suggestions outside of CoCs are mostly concentrated in the area between downtown Los Angeles and Santa Monica.

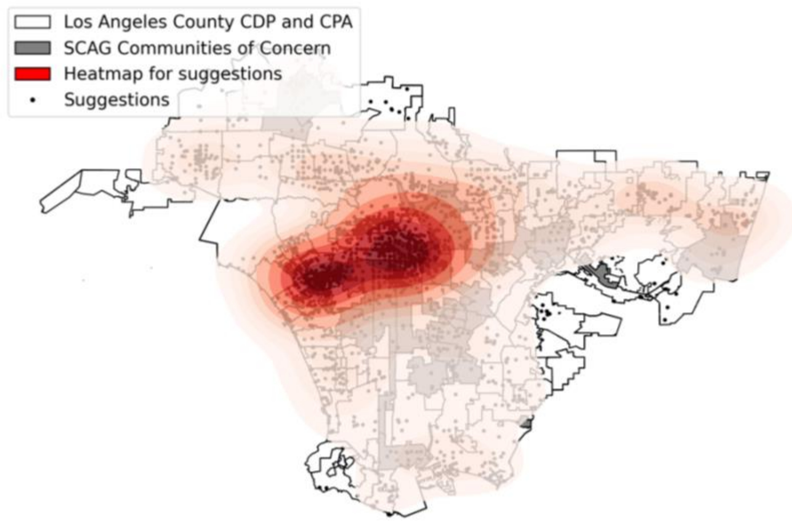

Figure 23. Heatmap for suggestions in Los Angeles County.

Figure 24. Comparison of heat map between suggestions within CoC and Suggestions outside CoC.

In Table 21, we compared the current stations and the suggested stations. Because the Los Angeles CDPs (Census Designated Places) and CPAs (Community Planning Areas) have huge variations in size and population, we compared the two systems in multiple metrics, including station counts, number of stations/suggestions per 10,000 people, number of SCAG tracts with station/suggestion coverage, and the areas of the SCAG regions with station coverage.

First, we found that the CoC tracts have a slightly higher proportion of suggested stations than current stations. In addition, the CoC tracts have the largest increase in the number of suggested stations per 10,000 people. Both suggested that the demand for more stations in CoC tracts is stronger than in non-CoC tracts. In terms of SAGA tracts, we see that the non-CoC tracts have the increased proportions of both the number of tracts and the area of tracts. This pattern, combined with the previous observation, shows the difference in demand of CoC tracts and non-CoC tracts. While bike stations in non-CoC tracts demanded more coverage of the service area, the bikeshare stations in CoC tracts demand more bike station services in a relatively smaller area.

Table 21. Statistics comparison between current stations and suggestions of Metro Bikeshare.

	Current Stations	Suggested Stations
Stations count by SCAG tracts		
CoC tracts	49 (22.8%)	599 (25.4%)
Other tracts	166 (77.2%)	1755 (74.6%)
Total number	215	2354
Stations per 10,000 people*		
CoC tracts	0.34	4.12
Other tracts	0.24	2.51
All tracts	0.25	2.79
Number of SCAG tracts with station coverage**		
CoC tracts	5 (31.25%)	26 (25.49%)
Other tracts	11 (68.75)	76 (74.51%)
All tracts	16	102
Area of SCAG tracts with station coverage (km^2)***		
CoC tracts	162.97 (28.32%)	805.17 (19.71%)
Other tracts	412.32 (71.67%)	3279.00 (80.29%)
All tracts	575.29	4084.17

Note: * This number is calculated by dividing the station count by the total number of populations of the tracts. The area of the case study has a total population of 8,435,423, out of which 1,454,586 people live in the CoC areas.
** A SCAG tract is selected if there exists at least one current/suggested station within the tract.
*** This section presents the total areas of the tracts selected from the above section “Number of SCAG tracts with station coverage”.

Comparing the distribution of suggestions in Figure 23 with the service area of dock-less bikeshare service (JUMP) in Figure 13, we found a significant overlap between the two distributions, with the area of the suggested stations almost fully covering the service area of the dockless bikeshare system. The service area of the dockless bikeshare systems takes around 23% of the total area of tracts with suggested stations in them. The service area of JUMP also covered the two hotspots of suggestions. This suggests that the area where the bike stations are mostly demanded is also the area with the service of the dockless bikeshare system. The demand also reveals that the dock-based system and the dock-less systems in the Los Angeles metro area are complementary to each other.

As Metro Bike does not allow users to label the purpose of their suggestions on its web-based suggestion system, we do not have the purpose information as we did in San Francisco. Due to this limitation, we are unable to perform the spatial similarity analysis in this section.

Discussion

Dockless Bikeshare Systems and CoCs

Based on the literature review, several critical barriers for bikeshare users in disadvantaged communities have been identified. Among those barriers, access to bikeshare services is discussed most frequently. The limited access to bikeshare service can be reflected in multiple dimensions, including not being covered by designed service areas, not enough stations/bikes within reasonable walking distance, and not frequent rebalance activities to meet bikeshare demand. Thus, this study is trying to compare both dock-based and dockless bikeshare systems from the aforementioned dimensions.

Overall, our analysis shows that the dockless bikeshare system tends to cover more area and a larger population of CoCs than the dock-based system. Even though the local government designates the service areas of both systems, the dock-based system can cover more CoC areas if the municipal government allows expanded coverage, and if the company is willing to site stations in the CoCs. Dockless systems still have the advantage of not requiring physical stations. Users of dockless bikeshare can pick up or return bikes in CoCs as long as the CoCs are situated within the service area.

In San Francisco, for JUMP Bike, the number of available bikes is, on average, greater in CoCs (high level) than in non-CoCs. JUMP Bike keeps an average of nearly 32.5% of its bikes in CoCs since its launch in 2018 (SFMTA Board of Directors 2018) and the average idle time within CoCs is shorter than that of non-CoCs. However, this is the opposite compared to Ford GoBike, because rebalancing activities are more frequent in the CoCs for JUMP Bike. Dockless systems need more frequent rebalances to meet potential demand. It is important to note that this service is provided even though the approximately 1,500 bikes operated by JUMP Bike are just about half of all bikes in service for Ford GoBike.

After analyzing JUMP Bike activities, we find that a greater proportion of rebalancing activities happen in CoCs for JUMP Bike than for Ford GoBike. JUMP Bike produces a comparable level of bike availability in CoCs as Ford GoBike considering JUMP Bike's greater service area and smaller bike fleet size. We also find that there are a certain number of users starting or ending their trips in CoCs, but outside the approved service area, which demonstrates potential demand. The flexibility of dockless bikeshare systems makes it possible for more users to make bikeshare trips as a replacement for other modes, especially between CoCs and non-CoCs, as reflected by the trip time analysis (Table 10). More importantly, we notice that the existence of e-bikes helps extend bikeshare service areas (e.g., hilly areas) and mitigates the bikeshare usage gap between the CoCs and other tracts.

To better compare the service levels of these two systems, we summarize all the findings related to these metrics in Table 22. Based on bike availability/idling, rebalancing, and bikeshare trips, we can see that dockless bikeshare systems have shown great potential for providing almost the same or even better level of bikeshare services for CoCs as they provide for other, non-CoC areas.

Table 22. Evaluation of two bikeshare systems in San Francisco.

Systems	Ford GoBike (dock-based) and JUMP Bike (dockless)
Service area	JUMP Bike covers twice areas as large as Ford GoBike within the boundary
Bike availability/idling	3. The same or even greater level of bike availability in CoCs in JUMP Bike after calibrating bike number and service area 4. Bike idling time is shorter through frequent rebalancing in JUMP Bike
Bike rebalancing	A greater proportion of bike rebalancing activities are related to CoCs in JUMP bikes
Bike trips	4. Almost the same level of trip generated or terminated within CoCs between Ford GoBike and JUMP Bike 5. Longer trip time because of flexibility in JUMP Bike 6. E-bikes in JUMP Bike may help mitigate the barriers faced by bikeshare users from CoCs

In Los Angeles, the two systems behave rather differently. The dockless JUMP bike has a larger service area in both non-CoC and CoC tracts, but it has most of it bikes deployed in Santa Monica and surrounding coastal areas, which are both rich communities and tourist attractions. The dock-based Metro Bike has more bike stations and operations in downtown Los Angeles. Since the JUMP service area is generated from idling bikes in the region, some of the regions can have a very limited number of bikes, causing the large variation in bike availability and idling times in JUMP (Table 13). Nonetheless, JUMP has managed to provide better service in non-CoC communities, while Metro Bike Share has a more equal service for all tracts. There is no significant difference between dock-based and dockless systems regarding trip durations. A detailed comparison can be found in Table 23.

In both cities, San Francisco and Los Angeles, we can see the same phenomenon that dockless bikeshare systems cover more tracts, including tracts identified as disadvantaged communities, than dock-based systems. However, there is a slight difference in dockless bikeshare systems serving CoCs between San Francisco and Los Angeles. The dockless system in San Francisco serves CoCs better than the dock-based one, while the situation is reversed in Los Angeles. One possible reason for this is the different nature of the two regions: San Francisco is a very compact city, where bike users can travel across all tracts with few obstacles, engaging in more activities across regions; on the other hand, the Los Angeles metro area has a relatively extended urban layout, making it extremely difficult to travel across different regions by bike, therefore activities are mostly restricted by where the bikes are deployed. Another reason is that the permitted service area of JUMP Bike in Los Angeles mainly covers the Santa Monica region, where there are limited disadvantaged populations. Thus, local governments should allow the permitted service area of dockless bikeshare systems to cover more CoCs when introducing new bikesharing services.

Table 23. Evaluation of two bikeshare systems in Los Angeles.

Systems	Metro Bike Share (dock-based) and JUMP Bike (dockless)
Service area	3. JUMP Bike covers significantly larger area (both CoC and non-CoC) than Metro Bike Share. 4. The two systems have different most-served areas: JUMP has most of its bikes deployed in the Santa Monica area where mostly rich communities are located; Metro Bike Share has three clusters of stations, with one of the clusters located in downtown Los Angeles where most disadvantaged communities are located.
Bike availability/idling	3. For bike availability, both Metro Bike Share and JUMP have larger number of bikes in non CoC tracts than in CoC tracts. 4. For bike idling time, Metro Bike Share has more consistent time variation in CoC tracts and non-CoC tracts; JUMP has larger variations in non-CoC tracts than in CoC tracts.
Bike rebalancing	The rebalancing activities in both systems follow a similar pattern: the areas with most bikes rebalancing out are also the areas with most bikes rebalancing in.
Bike trips	3. Metro Bike Share has a more even distribution in number of bike trips between CoC tracts and non-CoC tracts. JUMP bike has disproportionally more trips in non-CoC tracts. 4. Both systems have similar trip durations.

Dock-based bikeshare systems have proven to provide significant accessibility improvements for disadvantaged communities (Qian and Niemeier 2019). However, there are still limited stations sited in disadvantaged areas. Dock-based systems can provide service only if they have physical stations available. Dockless bikeshare systems overcome this access barrier faced by disadvantaged communities, but only to a certain degree because of the penalty fee outside the service boundary. From our quantitative analyses, we believe that dockless bikeshare systems could solve equity problems through a broadened service area and frequent rebalancing. However, there remain regulatory issues around dockless bikeshare systems, including how to manage them and how many bikes should be allowed? Dockless bikeshare companies should work together with local governments to design a dedicated plan to extend the system scale incrementally. This public-private partnership could help leverage funding for constructing and improving bike infrastructure in disadvantaged communities. Our results and methodology can assist local governments in monitoring dockless systems in terms of serving CoCs as they expand and in providing timely regulation requirements of private bikeshare companies.

Service Areas and Affordable Plan

JUMP Bike and Ford GoBike (or Metro Bike Share) both provide an affordable bikeshare plan (see Table 3 and Table 4). Note that Ford GoBike only accepts in-person enrollment and the affordable annual membership fee in Metro Bike Share is higher than other two systems (i.e., Ford GoBike and JUMP Bike). Despite limited access to the internet, the online enrolling option still can provide more accessibility. As reported by SFMTA in September 2018, 20% of total JUMP Bike trips were from in-person rentals, which suggests that even users with little access to smartphones are still renting JUMP Bikes (SFMTA Board of Directors 2018).

In Ford GoBike, 3,300 users out of 16,000 members (20%) took part in the Bay Area discount "Bike Share for All Program" (SFMTC 2019). The SFMTA report shows that users from the JUMP Bike Boost Plan (six trips per week) make three times as many trips as single rides (two trips per week) on average (SFMTA Board of Directors 2018). According to the same report, 55% of JUMP trips originated or terminated in a CoC, including CoCs not covered by the dock-based system in San Francisco. This proportion (55% for the first half of the 2018 year) is higher than what we observed in the trips during January and March in 2019. One possibility is that the growth of general users is faster than that of users from CoCs. The number of dockless bikes has increased from 250 in early 2018 to nearly 1500 in 2019. Even though the service area has remained the same over time, more general users may be attracted by a new travel mode. The promotion of the dockless bikeshare system has slowed since it was launched. However, our analysis still suggests that dockless bikeshare systems can compete with dock-based systems in terms of serving CoCs even though the system scale is small.

Suggestions for future promotion of dockless bikeshare in CoCs could include the integration of an in-person enrollment option for the affordable membership plan and keeping this fee as affordable as possible for CoCs. Community outreach activities should be used in advertising to users in CoCs since they may have limited access to the internet and smartphones. In addition, it is encouraged that local transit agencies partner with private bikeshare operation companies to allow shared pass or permit between transit and bikeshare systems.

Online Suggestions and Bikeshare Planning

As we can see from the analyses on online crowdsourced data, the suggestions from CoCs indicate that a significant proportion of demand for bikeshare is as a mode for work commuting. However, the current dock-based bikeshare station system in San Francisco has a more similar spatial distribution with the purposes of recreation and shopping. In non-CoC areas, the spatial distributions of current physical stations and primary bikeshare demand (work/school and fun) are identical. Thus, there is a gap between the supply of dock-based systems and the potential demand for work commuting in CoCs, which could be addressed by dockless systems. Local governments could leverage this online platform to regulate the planning of dockless bikeshare systems to cover potential demand in CoCs.

Moreover, it is important to acknowledge the bias of this online platform because low-income or disadvantaged communities are underrepresented. The disproportion of the suggestions from disadvantaged areas is consistent with a study by Piatkowski et al. (2017). If time and resources allow, an in-person poll collaborating with local churches, social service providers, and local communities could replace this online system to collect information from disadvantaged areas, considering potential access limitations to communication technologies. An equitable design of bikeshare systems needs more voices from the traditionally underrepresented populations.

Last, participation in the online suggestion platform is not as high as expected. This problem might be overcome with a continuous promotion or outreach effort. Continuous participation is important because feedback is dynamic, and topics of concern change over time. In addition, planners or service providers must have the capacity to interpret the crowdsourced data and turn it into practical actions.

Conclusion

We used San Francisco and Los Angeles as case studies since both of these cities have dock-based and dockless bikeshare systems running concurrently. First, we use web scraping algorithms to download the bikeshare system data for both systems. Through mapping the actual service area of the dockless bikeshare system, we find that the dockless bikeshare system results in a larger service area than Ford GoBike (or Metro Bike Share) even though it has a service boundary restriction. We analyze the spatial distribution of available bikes, bike idle time, bike rebalancing, and trip origins/destinations for both systems. By comparing the differences in the service levels and trip activities between dock-based and dockless systems, we note that the dockless system provides a greater average number of available bikes in the CoCs than in non-CoCs in San Francisco, considering its total number of bikes (which is about half the number of bikes in the dock-based system). But in Los Angeles, the dockless system provides fewer available bikes in CoCs than in non-CoCs. We also show that for the dockless bikeshare, bike idling time on average is shorter in the CoCs than in non-CoCs, which is not significant in Ford GoBike and Metro Bike Share. In San Francisco, the dockless bikeshare system also seems to be able to attract a greater share of potential bikeshare trip demand in the CoCs because of a broader service area and frequent bike rebalancing. In Los Angeles. the Metro Bike Share appears to attract more tip demand in the CoC due to comprehensive bike station coverage and active bike rebalancing. More importantly, the e-bikes in JUMP Bike can help mitigate the bikeshare usage gap between CoCs and non-CoCs in San Francisco.

As new technologies (e.g., dockless systems, scooters, mopeds) of shared mobility services emerge, we need to compile and analyze comprehensive service level metrics instead of solely depending on service areas and trip numbers to evaluate service levels. In this work, we show ways to compare service levels across two kinds of bikeshare mobility services, dock-based and dockless. Through this comparison, we extend knowledge about dockless bikeshare systems, which show potential to offer equitable services for CoCs through frequent bike rebalancing activities, despite the fact they are generally more regulated by local governments. Our results also provide policy insights for local municipalities on how to best support and properly regulate dockless bikeshare systems to improve equity.

Even though this study only examines two cities in California, the analysis framework can be adopted in any other city. Currently, most of the dock-based bikeshare systems are a cooperation between local governments and private companies, while dockless bikeshare systems are mainly owned by private companies. The difference may be caused by the fact that dock-based bikeshare systems need to get access to land space and physically build a station. Thus, a cooperation with municipal governments will make this process easily. On the other hand, dockless bikeshare systems do not have such restriction, which do not need involvement of local governments. To promote this sustainable micro-mobility, local governments can consider leverage the advantaged of dockless systems and meanwhile regulate them to provide more equity access to CoCs.

In addition, this research examined online suggestion data, which reflects potential bikeshare demand. By comparing the spatial distributions of current stations and suggested locations, we can identify the demand gaps in CoCs due to the space restriction of dock-based bikeshare systems. In CoC areas, the leading purpose of suggested stations is work/school, while the current dock-based stations have not sufficiently covered that bikeshare demand. Dockless bikeshare systems, without restrictions in service areas, could address this limitation of dock-based bikeshare systems.

The main limitation of this research results from data shortcomings, e.g., the unavailability of user information in JUMP Bike data. In San Francisco and Los Angeles, there are some tracts that are both CoCs and tourist areas. Bikeshare trips may be generated by tourists instead of local residents. Greater access to user profiles, e.g., users' demographic information and how frequently a user makes bikeshare trips, would refine our comparisons and provide additional insights on the travel behaviors of users from CoCs. A survey study targeted at residents from CoCs is a good next step for future research.

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Data Summary

Products of Research

The comparative analyses between dockbased and dockless bikeshare system required the use of bikeshare data from Ford GoBike, Metro Bike and JUMP Bike in San Francisco and Los Angeles. Dockbased systems providers offer trip data at their websites, including information about trip start day and time, end day and time, start station, end station, bike id, and rider type (annual member and day pass users). Operators do not provide information on bike availability or rebalancing activities. For the dockless data, the team gathered information through the General Bikeshare Feed Specification (GBFS). The GBFS provides real-time bike information (including bike id, location, battery level, and service status), and the number of available bikes in available hubs in a city. We developed a web-scraping (web data extraction) tool for the systematic and continuous collection of the real-time information from GBFS (e.g., JUMP Bike). The authors used data from January to March, 2019.

Additionally, the authors used data from public online portals where users can suggest potential bikeshare station locations and comment on existing ones.

The analyses also required gathering socio-demographic information in the study regions to identify communities of concern, among other operational attributes.

Data Format and Content

Bikeshare (dockbased and dockless data). The team created datasets for the two systems in San Francisco, and the two systems in Los Angeles. The files are provided in .csv format.

Socio-demographic data. The authors generated geographic information system (GIS) layers for the San Francisco, and Los Angeles to identify bikeshare stations, and communities of concern. These files are provided in share file format.

User comments. The authors compiled and cleaned the user comments for Ford GoBike and Metro Bike systems. These files are provided in .csv format.

Data Access and Sharing

The data used in this work follows the copyrights and use terms from JUMP Bike, Metro Bike, and Ford GoBike. The files uploaded to Dryad are gathered from their public or open access systems and are provided as consolidated file sources to the research community and to replicate the findings of this research.

Interested individuals will be able to access the data available through Dryad and should contact the Principal Investigator, Dr. Miguel Jaller prior to accessing the data. The data should not be hosted in other locations and should only use the Dryad repository.

Users of the data should reference the system providers, and the data repository in Dryad. The DOI for the data is: https://doi.org/10.25338/B8X064

Reuse and Redistribution

Dr. Miguel Jaller and the other co-authors of the work (identified in this Final Report) hold the intellectual property rights to the data generated by the research. Services providers hold the right to the bikeshare data, and the online portal comments data.

Data will not be able to be transferred to other data archives besides the ones approved by the PI and Co-PIs. The data can be used by anyone with proper referencing to the authors.