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Enhancing equitable service level: Which can address better, dockless or dock-based Bikeshare systems?

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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 the extent to which dockless systems can help mitigate barriers to bikeshare for disadvantaged populations. Using San Francisco as a case study, because the city has 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 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. Our results provide policy insights to local municipalities on how to properly regulate dockless bikeshare systems to improve equity.

1. Introduction and background

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 users to 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 in a restricted 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 experience 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 all of 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

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stations (Médard de Chardon et al., 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 & Jaller (2020). 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 the potential impacts of 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 city of San Francisco as a case study 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.

2. Literature review

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 et al., 2019a). 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 (Bernatchez et al., 2015; Buck, 2013; McNeil et al., 2017). 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 et al., 2018; Smith et al., 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 improvements 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).

i think spatial equity is more interesting

There is a limited number of studies focusing on equity problems for dockless systems. Hirsch et al. (2019b) 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 when operating at the same time.

3. Case study and data description

3.1. Case study city and bikeshare systems

This research uses San Francisco city 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 since 2013, which provides 850 e-bikes and around 6200 classic bikes, with 540 stations across the Bay Area. In San Francisco city, this system had 2813 bikes in early 2019, among which 250 were electric bicycles. In 2018, Motivate was purchased by (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 the Metropolitan Transportation Commission (MTC) designated CoCs (Baywheels, 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 with 15 bike hubs with bike docks that have charging capabilities. Currently, there are around 1500 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 min of daily ride time), for households identified as disadvantaged by the CalFresh program (Cal GOV, 2019), PG&E, and SFMTA (JUMP, 2019a) (Table 1).

Even though both systems provide affordable membership plans, there are three main differences between them. First, Ford GoBike provides its plan members a 60-min grace period of free riding for every trip, while JUMP Bike only provides a 60-min 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 min) to avoid extra charges after the grace period if there are available stations along the trip. Finally, JUMP Bike allows users to

Table 1
Affordable membership plans provided by both systems.

System	Ford GoBike bikeshare (Dock-based) (L. Inc., 2019)	JUMP Bike (Dockless) (J. B. Inc., 2019)
Price	$5 annual membership ($5 month in the second year)	$5 annual membership ($5 month in the second year)
Benefit	first 60 min of each trip	60 min of ride time per day
Charge	Rides longer than 60 min will result in additional fees of $3 for each additional 15 min or potential account suspension	$0.15/min after the initial 60 min (or $2.25 for each additional 15 min). $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 on 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

Table 2
Factors used to classify CoCs. - defined by local gov (regional planning commission)

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%

enroll in their affordable plan online, but Ford GoBike only accepts in-person enrollment. Table 1 compares the characteristics of affordable membership plans for specific communities in both systems.

3.2. Bikeshare system data

The analyses require data from both bikeshare systems. However, the data from the two bikeshare systems in San Francisco are not in the same format as well as in other cities across the US.

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 these trip-based 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 following 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 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).

3.3. 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). In San Francisco, the MTC provides its own definition of disadvantaged communities for the transportation field. In a recent report on dockless bikeshare evaluation 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 (Table 2).

Specifically, a census tract will be identified as a CoC if its "Low-Income" and "Minority" shares are over the threshold values or 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 make it more understandable. The first example of CoCs can be a census tract with 80% (> 70%) population as a minority and 40% (> 30%) households under 200% Federal poverty line. Another example of CoCs is a census tract that has 40% (> 30%) households being low-income and 30% (> 20%) population with limited English proficiency, 20% (> 10%) zero-vehicle households, 20% (> 10%) 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 (Fig. 1). Furthermore, within the CoCs, the MTC

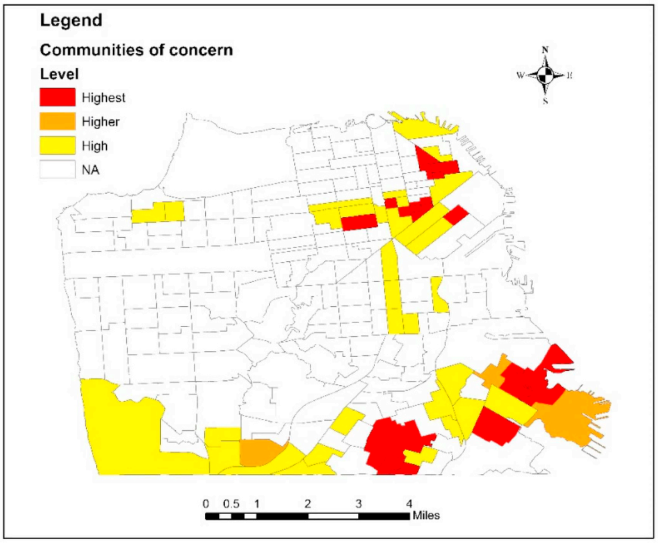

Fig. 1. Map for CoCs.

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.

4. Methodology

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, the 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' performances, measure how well/poorly CoCs are served, and identify where barriers exist and how they might be removed.

4.1. 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-m catchment buffers for bikeshare stations (Qian and Jaller, 2020; Wang and Akar, 2019). The 400-m range is selected based on the fact that people tend to walk to bikeshare stations within one-quarter miles (Cohen, 2016; García-Palomares et al., 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.

4.2. Bike availability, idling, rebalancing, and trips

Ford GoBike provides 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 (Fig. 2). Fig. 2 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 Fig. 2, 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.

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 (Fig. 3). 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 Fig. 3).

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 1712 trips per day (JUMP, 2019b). Additionally, we remove "trips" with a duration longer than 4 h or with an increasing battery level. After

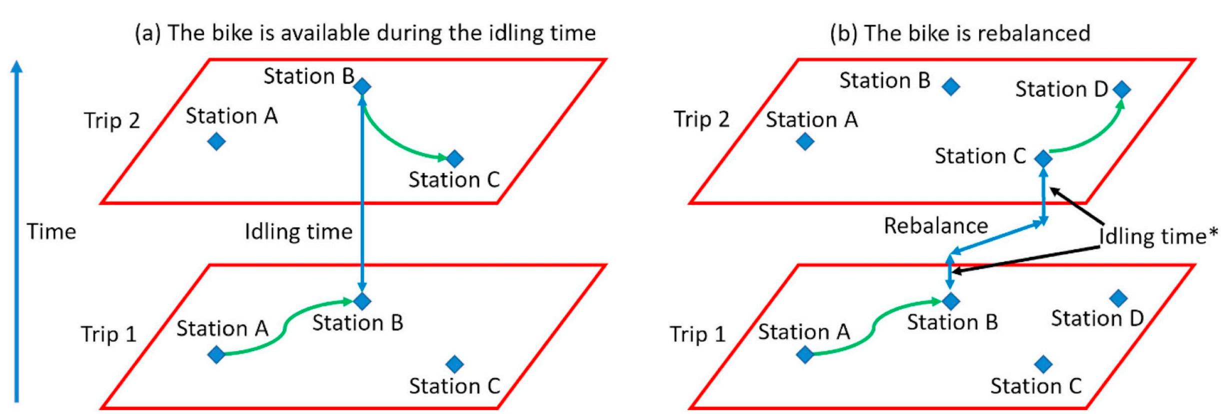

Fig. 2. Calculation of bike availability, idling time and bike rebalancing for Ford GoBike (dock-based).

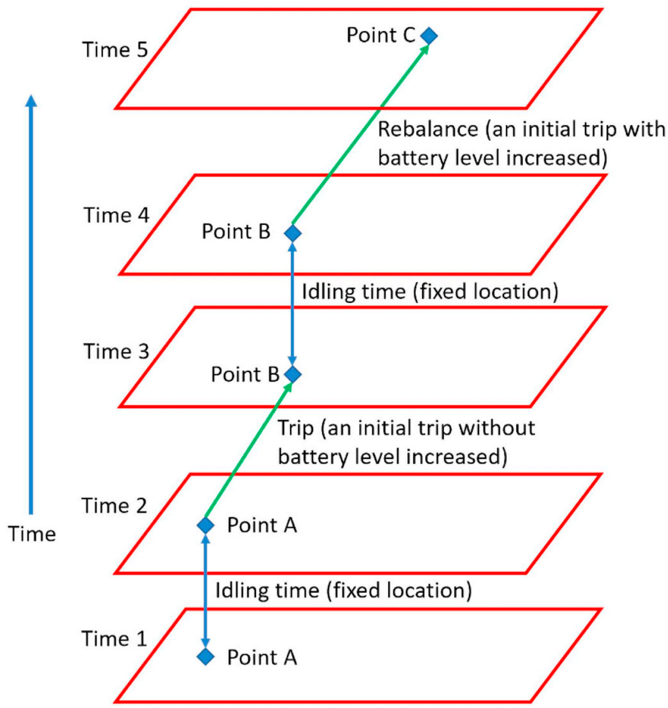

Fig. 3. Calculation of bike availability, idling time, trip and bike rebalancing for JUMP Bike (dockless).

analyzing trip data, we identify those trips over 4 h to be outliers, and 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, if a trip originating at a point A, ending at a hub, and another trip originating at the hub and ending at a point B, it 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.

4.3. Evaluation framework

Fig. 4 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. Moreover, 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 service levels of both bikeshare systems in terms of equity, considering the aforementioned 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.

5. Empirical results

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.

5.1. Bikeshare station distribution and service area

The left panel in Fig. 5 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 Fig. 5 is the serviced 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 (Tables 3 and 4). 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 serviced 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 3 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.

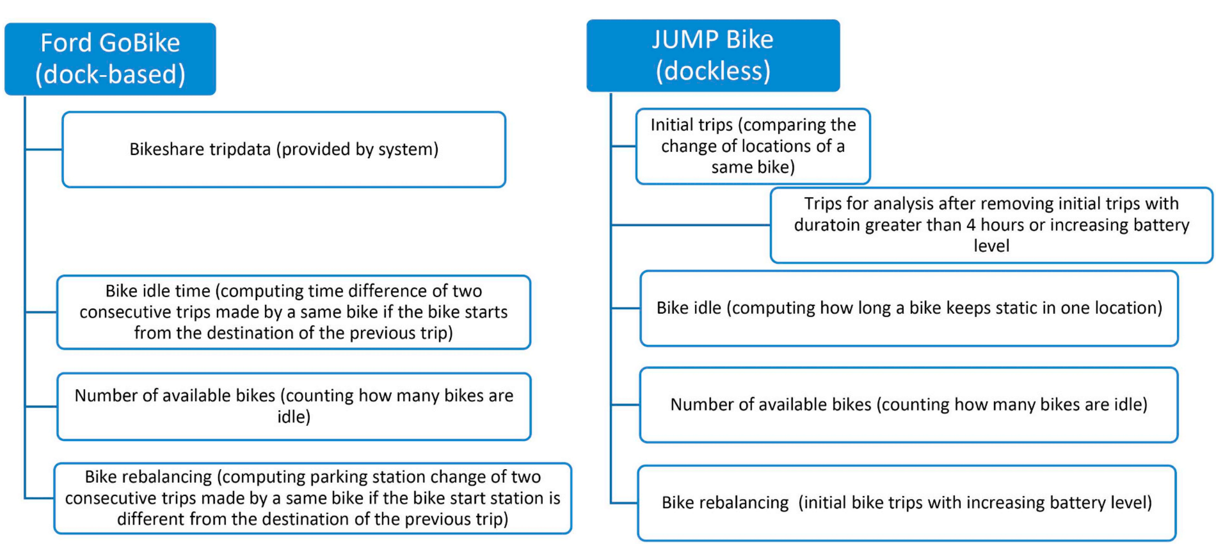

Fig. 4. System data calculation methodology.

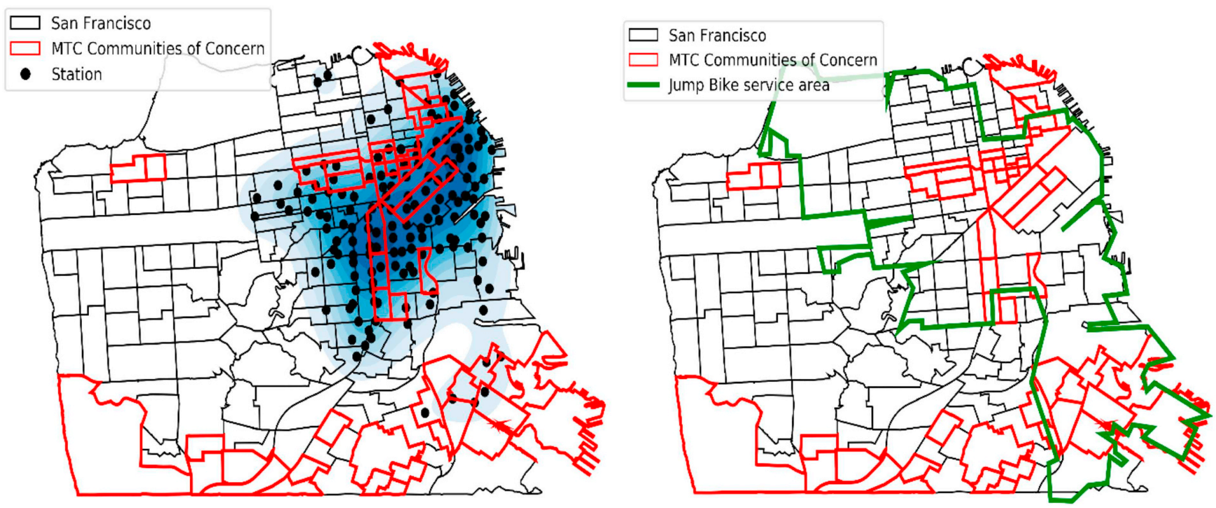

Fig. 5. Service areas of Ford GoBike (dock-based, left) and JUMP Bike (dockless, right).

Table 3
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	253701	508335
	All CoCs	90583	140686
	High CoCs	69281	84405
	Higher CoCs	4249	4725
	Highest CoCs	17053	51556
	Other	163118	367649
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.

5.2. Bike availability and idle time

We calculate daily bike availability and for 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 4 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 significant 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. Besides, JUMP Bike covers a designated service area that is approximately twice as large as Ford GoBike's service area. The average number of the 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 considering the small scale of its bike fleet.

Table 5 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 to estimate idling. We ignore the idling time for potential idling before and after a rebalancing activity (the right panel in Fig. 2). For Ford GoBike, the average idling time in non-CoC tracts (372.5 min) tends to be longer than those found in all of the CoCs (367.2 min), especially for the CoCs at a high level (349.3 min). The statistical test shows that the difference is significant at the 90%

Table 4
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	–[a]	–	–	–	–
		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[b]	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

[a] "–": there is only one tract in this category.
[b] The left number is for the tracts within the service area while the right one is outside the service area.

Table 5
Statistics for bike idle time (minute) on average.

Systems	Bike idle time/min		Bike count	mean	min	25%	50%	75%	max
Ford GoBike (dock-based)	CoCs	All	130,813	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	2810.5	2.19	539.1	1208.0	2600.0	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	53,107/2731[a]	120.2/162.9	0.5/0.5	3.3/4.0	21.1/29.1	84.1/115.0	15.6d[c]/15.5d
		High	41,422/2692	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/– –[b]	20.4/– –	97.0/– –	11.0d/0.38d
	Other tracts		140,774/4639	163.4/263.4	0.27/0.5	4.9/2.0	31.5/37.5	138.0/243.2	24.7d/12.3d

[a] The left number is for the tracts within the service area while the right one is outside the service area.
[b] "–": there is only two data point in this category.
[c] The unit is a day (d) instead of a minute to be concise.

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 the JUMP Bikes are rebalanced by system operators or used by users more frequently than Ford GoBike.

Table 6
Rebalance classification.

Systems	Ford GoBike (dock-based)	JUMP Bike (dockless)
Within CoCs	1956 (5.1%)	2775 (11.0%)
From CoCs to non-CoCs	4438 (11.7%)	4117 (16.3%)
From non-CoCs to CoCs	6641 (17.5%)	3887 (15.4%)
Within non-CoCs	24952 (65.7%)	14445 (57.3%)
Total	37987	25224

5.3. 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 (Fig. 6). Most of the rebalancing activities are within non-CoC tracts (Table 6). The proportion of rebalancing within the CoCs is only 5.1% (1956/37,987), 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).

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 (Fig. 7). 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 6), 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 (2775) is also greater than that (1956) of Ford GoBike. This supports our earlier observations about bike availability and idle time in the CoCs.

5.4. Bikeshare ridership

Trip distribution is an important feature to measure bikeshare coverage of CoCs and how users from CoCs utilize the service. For both

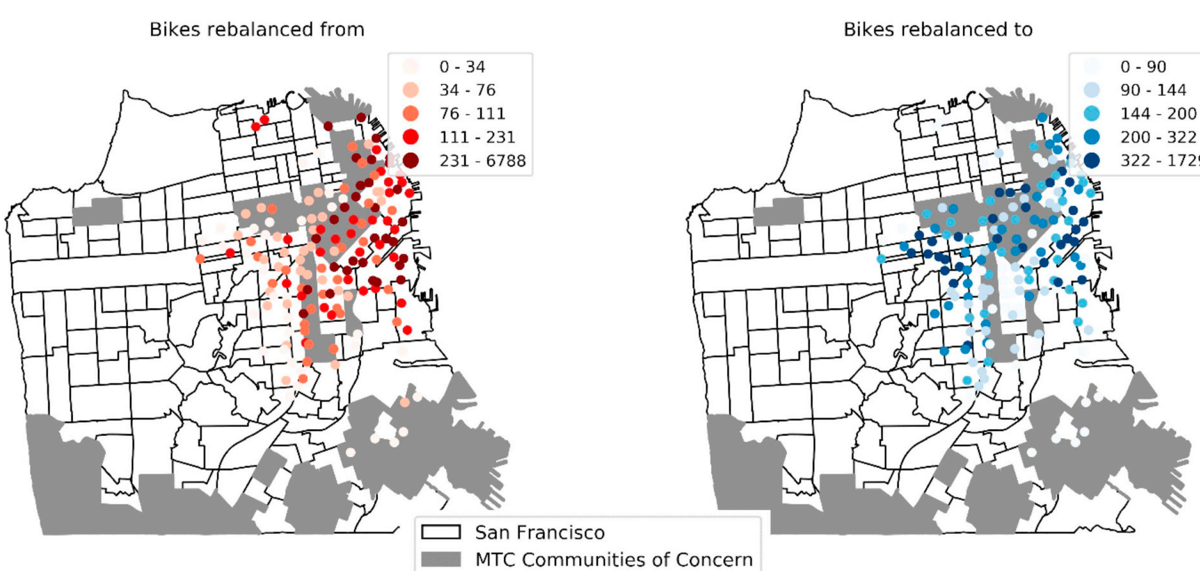

Fig. 6. Distribution of bike rebalancing origins and destinations in Ford GoBike (dock-based).

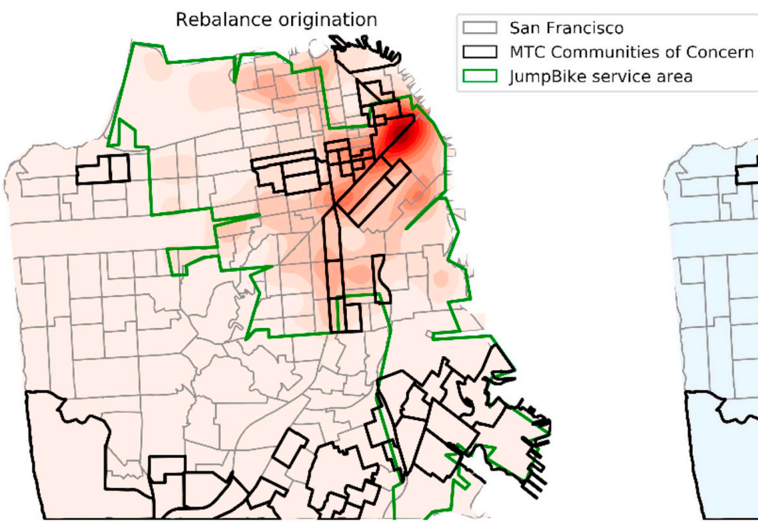

Fig. 7. Kernel density estimation of the distribution of bike rebalancing origins and destinations in JUMP Bike (dockless).

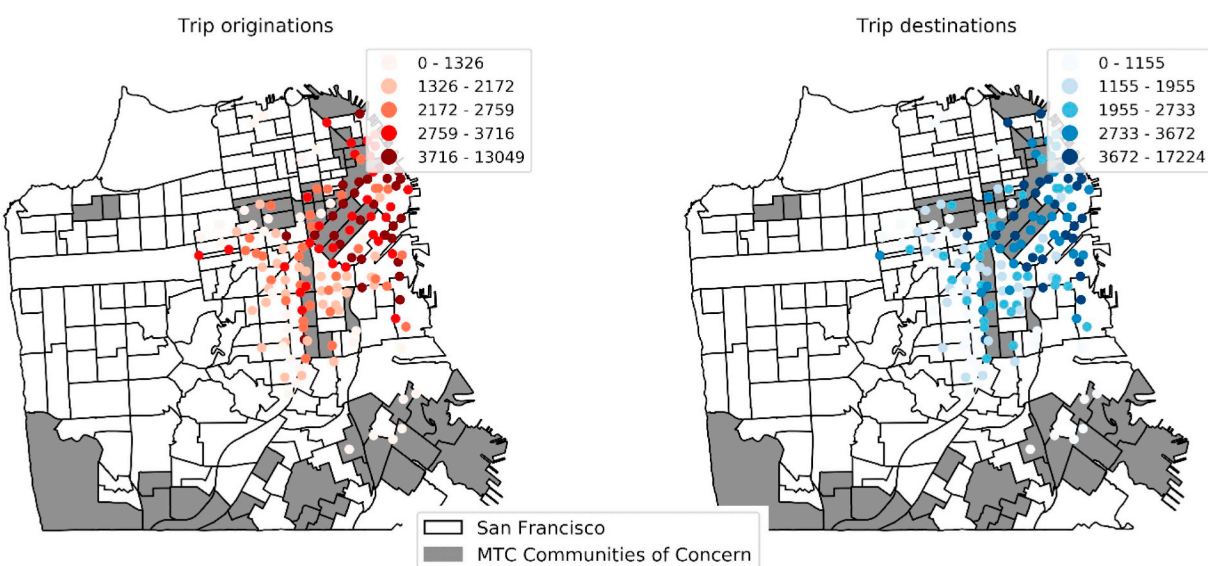

Fig. 8. Distribution of trip origins and destination in Ford GoBike (dock-based).

systems, the areas with larger trip generation are also where users are most likely to end their trips (Figs. 8 and 9). 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 7 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 8 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 (1986/2016) are significantly larger than those of trips within non-CoCs (1560). 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 been previously made using other modes.

Since San Francisco is a hilly city, electric bikes may be more attractive for 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 originations and destinations are almost the same for a single census tract (Table 7), we only pay attention to trip originations. As we can see in Fig. 10, 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.

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 & Jaller (2020). The results are shown in Table 9. The fact that elevation has a negative effect on bikeshare ridership is illustrated by Fig. 10. However, the magnitude of this effect is smaller

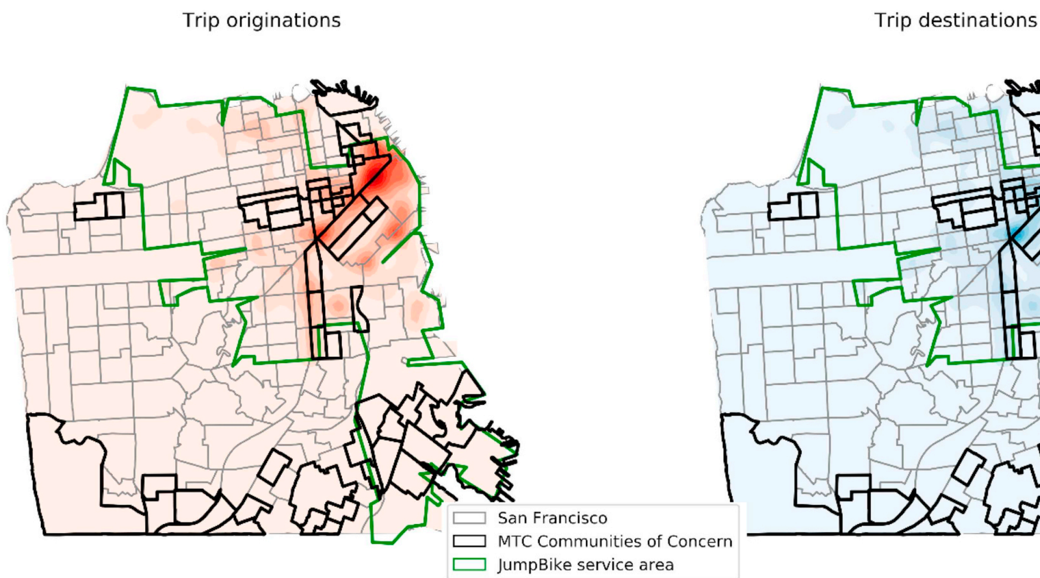

Fig. 9. Kernel density estimation of the distribution of trip origins and destinations in JUMP Bike (dockless).

Table 7
Statistics for bike trip numbers.

System	Tract types	Trip originations	Ratio to other tracts	Trip destinations	Ratio to other tracts
Ford GoBike (dock-based)	All CoCs	139896	42.9%	137797	42.0%
	High CoCs	127260	39.0%	125212	38.2%
	Higher CoCs	213	0.06%	238	0.07%
	Highest CoCs	12423	3.8%	12347	3.8%
	Other tracts	326073	100%	328172	100%
JUMP Bike (dockless)	All CoCs	44855/2128[a]	38.3%/59.4%	44620/2316	38.2%/59.1%
	High CoCs	34900/2109	29.8%/58.9%	34493/2291	29.5%/58.5%
	Higher CoCs	484/18	0.4%/0.5%	464/24	0.4%/0.6%
	Highest CoCs	9471/1	8.0%/0.0%	9663/1	8.3%/0.0%
	Other tracts	117076/3580	100%/100%	116787/3917	100%/100%

[a] The left number is for the tracts within the service area while the right one is outside the service area;

Table 8
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	14173
	2	748	61	399	589	864	14272
	3	745	62	409	608	869	14235
	4	747	61	349	566	881	14375
JUMP Bike (dockless)	1	1200	59	121	569	1439	14374
	2	1986	60	847	1319	2158	14397
	3	2016	59	853	1326	2187	14399
	4	1560	13	240	1013	1906	14399

for JUMP Bike. Besides, the CoCs categories (High/Higher/Highest) play a less important role in determining JUMP Bike usage than Ford GoBike usage, no matter in terms of 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.

6. Discussion

6.1. Dockless bikeshare systems and CoCs

Our analysis shows that in San Francisco 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 CoCs 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.

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 with approximately 1500 bikes operated by JUMP Bike, just about half of all bikes in service by 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. Besides, 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 the CoCs and non-CoCs as reflected by the trip time

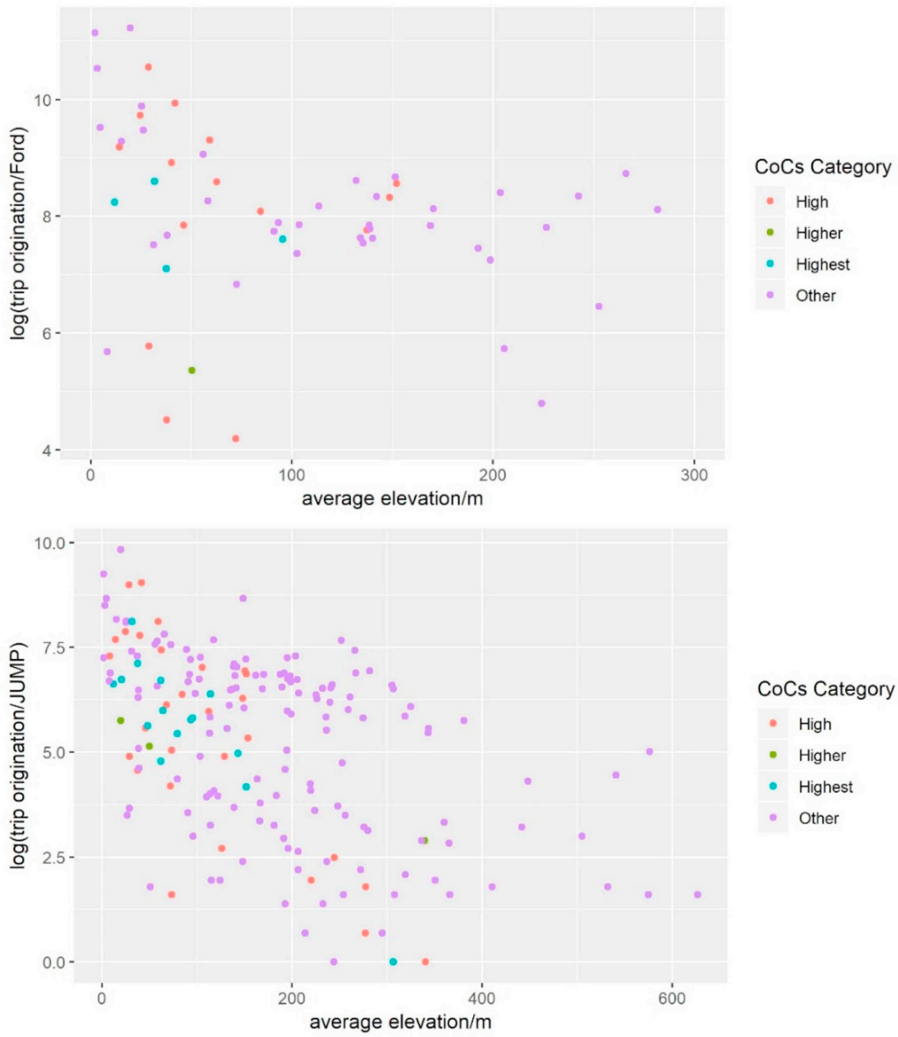

Fig. 10. Trip origination per census tract against average elevation.

Table 9
Annual bikeshare ridership estimation models for trip originations.

Variables	Ford GoBike (dock-based)		JUMP Bike (dockless)	
	Coefficient	Significance	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	

Significance levels: 0.0: ***; 0.001: **; 0.01: *; 0.05: ·.

analysis (Table 8). More importantly, we notice that the existence of e-bikes helps extend bikeshare service areas (e.g., hilly areas) and mitigate 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 10. 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.

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 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 step by step. 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.

6.2. *Affordable plan*

JUMP Bike and Ford GoBike both provide an affordable bikeshare plan (see Table 1). The main difference between the plans is that JUMP Bike allows a user to enroll online, while Ford GoBike only accepts in-person enrollment. 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

Table 10
Evaluation of two bikeshare systems.

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	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

smartphones are still renting a JUMP Bike (SFMTA Board of Directors, 2018).

In Ford GoBike, 3300 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. Community outreach activities should be used in advertising to users in CoCs since they may have limited access to the internet and smartphones.

6.3. *Potential influence of company funding structures*

In many US cities, dock-based bikeshare systems are mainly public-private partnerships. In our case study, Ford GoBike was originally funded by public funding from various sources, including MTC and the Bay Area Air Quality Management District. As a result, Ford GoBike needs to work with local officials, community groups, civic associations, and others to determine GoBike specifications and station locations for the Bay Area. However, JUMP Bike is a subsidiary of Uber (a Transportation Network Company), which is heavily funded by venture capital. Those venture-funded systems typically have a mandate to gain market share early to maintain more funding.

These funding structures may influence the sustainability of the patterns observed in this study. JUMP Bike still keeps extending its system in San Francisco and other cities in the US. We are not sure if JUMP Bike can continue to target more disadvantaged populations as higher expectations of market share and revenue from private funding sources. Thus, local governments should keep monitoring the performance of both bikeshare systems in terms of serving disadvantaged communities. The metrics introduced in this study can quantify the service levels and assist local governments with this process.

7. Conclusion and future work

We used San Francisco as a case study since the city has both 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 JUMP Bike, we find that the dockless bikeshare system results in a larger service area than Ford GoBike even though it has a service boundary restriction. We analyze the spatial distribution of available bikes, bike idle time, bike rebalancing, and trip originations/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 at a high level than in non-CoCs, considering its total number of bikes (which is about half he number of the dock-based system). 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. 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. More importantly, the e-bikes in JUMP Bike can help mitigate the bikeshare usage gap between CoCs and non-CoCs in a hilly city.

As new technologies (e.g., dockless systems) of shared mobility services emerge, we need comprehensive service level metrics, e.g., bike availability, idle time, and rebalancing, 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 shared mobility services. 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 to local municipalities on how to best support and properly regulate dockless bikeshare systems to improve equity.

The main limitation of this research results from the shortcoming of the data, e.g., the unavailability of user information in JUMP Bike data. In San Francisco, 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 comparison and provide additional resolution on travel behaviors of users from CoCs. A survey study targeted at residents from CoCs is a good next step for future research.

Declaration of Competing Interest

None.

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