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# Impacts of the COVID-19 Pandemic on Bikeshare Usage by Rider Membership Status Across Selected U.S. Cities

**Tung Vo[1], Natalia Barbour[2], Lori Palaio[3], and Michael Maness[1]**

**Abstract**

Bikesharing is a popular transportation mode for people to commute, for leisurely travel, or for recreation purposes in their daily tasks. Throughout 2020, the COVID-19 pandemic had significant impacts on bikeshare usage in the United States. Previous studies show that the pandemic negatively affected bikeshare activity patterns. To examine the effects of the pandemic on bikeshare behavior across membership types, this study investigated trip volume- and trip duration patterns of both members and nonmembers of five bikeshare systems across the United States. The results showed that member ridership significantly decreased throughout the pandemic, but nonmember ridership tended to be stable. It was also found that trip durations increased across both groups throughout the pandemic. Additionally, inferences were made to determine the level of support for a reversion to prepandemic normality as the pandemic progressed and reopening occurred in phases. The findings from this study could benefit bikeshare agencies in developing postpandemic recovery strategies.

**Keywords**

pedestrians, bicycles, human factors, bicycle transportation, bikesharing, modeling and forecasting

Because of the magnitude and severity of the COVID-19 pandemic (henceforth referred to as "the pandemic"), all mobility systems have been disrupted in ridership and operation. Although social distancing was a necessary precaution to slow down the spread of the virus, many people were obliged to continue traveling into and around cities owing to the nature of their profession or other external circumstances. Furthermore, much of the economy—including businesses, retail, and dining—relies on people visiting their premises and actively consuming their goods and services. Because the pandemic has dramatically changed the way that economic and social systems run, systems all over the world have shifted to a dynamic state of operations and management, requiring stakeholders to make adjustments and behavioral shifts (*1*). In response to public health recommendations, citizens who were mobile before the pandemic had to reassess their mobility needs and safety. Outdoor, active modes such as bikesharing systems that allowed maintenance of social distancing naturally became attractive alternatives to public transit and thus experienced a shift in user behavior (*1–3*).

Consequently, drastic changes have become apparent in people's mobility choices (i.e., lifestyles with respect to mobility, activity-travel habits, travel frequency) among other aspects of their activity-travel behavior (*4*). For example, Hadjidemetriou et al. indicated that most UK government measures were directly or indirectly connected to human mobility, with mobility decreasing as the government announced more restrictive measures, stabilizing at around 80% of pre-Lockdown levels (*5*).

The pandemic affected transit modes differently. High passenger density and enclosed spaces meant public transport provided prime conditions for person-to-person transmission, presumably much higher than other transport modes, such as bikesharing (*6*). In prepandemic research that looked at substitution effects between

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transit and bikeshare, Saberi et al. measured the impact of a subway strike on the mobility patterns of London's bikesharing system in 2015 (*7*). They found an 85% increase in the number of bikesharing trips and a substantial increase in average trip duration from 23 to 43 min. Dramatic decreases in transit ridership also occurred during the 2003 SARS outbreak in Taiwan (*8*). In trying to understand the changes in bikesharing behavior and demand during the pandemic, it is therefore important to place mode choice in the context of other modes, as they all tend to work together to deliver the mobility of a particular region.

Opportunities for increased bike usage because of the pandemic have been discussed and observed by the transportation field. De Vos suggested that the promotion of active travel that meets social distancing criteria could be a potential solution to maintaining a satisfactory level of well-being (*9*). Although limited at the time of this study's conception and analysis, literature on how the COVID-19 pandemic has affected the transportation sector and mobility in individual sectors, such as tourism and commute travel, has been growing as more data have been collected (*10*, *11*). Campisi et al. studied attitudes and stated preferences toward biking and found that a total of 61.3% of participants agreed that there would be greater use of bikes in Italy after the Lockdown compared to prepandemic (*12*). Molloy et al. analyzed changes in travel patterns in Switzerland 1 month into the pandemic and found that the overall number of workday trips had decreased, whereas trip duration remained relatively constant, except for bicycle use (*11*). Finding changes in biking behavior was consistent across the aforementioned studies and, although these authors did not exclusively address bikesharing usage, they offer interesting insights into how typical travel modes (e.g., cars, public transit) shifted toward more active ones.

This study sought to further explore and document the impacts of the COVID-19 pandemic and of government responses on bikeshare system usage and user behavior. It explored the impacts on ridership and median trip duration across five U.S. cities: Boston, MA, Chicago, IL, Los Angeles, CA, Minneapolis, MN, and Washington, D.C. Additionally, ridership and usage behavior were explored across different user types: system members (subscribers) and nonmembers (nonsubscribers). Importantly, this study examined the effects of COVID-19 on the recovery of each system during the reopening phases in relation to ridership and trip duration. The findings from this study will provide insights for decision makers of both cities and bikeshare systems to develop or adjust plans that will meet people's travel needs should any activity disruption—such as COVID-19, other pandemics, or natural disasters—occur in the future.

To examine the effects on bikeshare usage in these systems, the pandemic was split into five phases: First Cases, Lockdown, Phase 1, Phase 2, and Phase 3. The linear regression models of ridership and median trip duration were estimated at the membership level (member and nonmember). Additionally, two hypotheses—ridership increases throughout the reopening phases, and trip durations vary throughout the reopening—were posited, to further test the effects of the pandemic on bikeshare usage across the reopening phases. The results showed that member ridership typically did not rebound to prepandemic levels as the reopening phases progressed, except in Minneapolis. Additionally, the number of nonmember users did not bounce back to prepandemic levels except in Washington, D.C., which experienced a statistically significant increase. Both member and nonmember users were found to make longer trips during the pandemic.

## Literature Review

Overall, mode usage patterns have changed globally during the pandemic. Hensher observed that Mobility as a Service—including ride-, car-, e-scooter-, and bikesharing—observed a wholesale reduction in their use (*13*, *14*). Since COVID-19 exposure varies by mode, ridership levels exhibited a varying sensitivity of responses. With reference to bikeshare, ridership for commuting decreased sharply, whereas there were mixed results for the impacts on recreation and leisure. Much focus has been on the rebound effect (or confirming whether this is possible) after Lockdowns. Chai et al. examined how the pandemic affected bikesharing systems in Beijing (*15*). The authors concluded that shared bike usage was gradually rebounding during the mitigation phase. Although the recovery rate was not uniform in all districts and was concentrated mostly in urban districts, there were different patterns between weekdays and weekends. They found lower bikeshare usage at weekends.

Some have attributed this rebound to differences in exposure risk between modes. Teixeira and Lopes compared March 2020 ridership changes between bikesharing and subway use in New York City; bikesharing was found to be more resilient to change than the subway (*6*). The New York bikesharing system suffered less significant ridership loss, and its average trip time duration increased. Shamshiripour et al. studied risk perception in the context of transport and COVID-19 (*4*). Personal vehicle usage was associated with the lowest perceived risk of exposure, followed by cycling with personal (non-shared) bicycles and walking. Additionally, respondents perceived that bikeshare trips were less safe than trips made by personal bicycle, but safer than public transit or ride-sourcing services. This decrease in bikesharing ridership was not only found in the United States, but in

Europe. Li et al. analyzed data on micromobility (i.e. docked and dockless bikesharing, scooter sharing) from Zurich, Switzerland, up until April 2020 and found decreased demand for shared micromobility services during the COVID-19 period (*16*). Interestingly, the researchers also found that trip distances and -durations increased, thus indicating that this mode possibly served as a viable substitute for public transport. In relation to activity type, Li et al. also found that recreational activity experienced increased ridership during COVID-19 whereas leisure and shopping trips decreased (*16*). In Philadelphia, PA, Barbarossa also observed increases in single ride average daily distance during the pandemic, thus suggesting an increase in more casual trips (*2*).

Limited research has been conducted on the phases of reopening, partially because of the differences in policies across cities and regions. Padmanabhan et al. examined the impacts of COVID-19 in three different phases (no COVID cases, cases increasing, and cases decreasing) and found that the number of bike trips decreased while the average trip duration increased during the pandemic (*17*). Fuller et al. conducted a survey into cycling activity during the pandemic shutdowns in Australia (*18*). They found that more cycling activity was for exercise and well-being instead of for transport among respondents. Wang and Noland examined the effects of COVID-19 on the member and casual users of Citi Bike in New York City during the Lockdown and the four reopening phases (*19*). They found fewer member trips being taken owing to the shift to working from home and slightly higher numbers of casual trips during these periods. Qiao also found that the trip purpose shifted from commuting to recreational after the COVID-19 outbreak (*20*). The findings from these studies suggest that the restrictions and policies during COVID-19 significantly affected bikeshare usage as a consequence of the changing travel needs and -behavior of bikeshare users. These studies, however, only focused on the before period and during Lockdown and did not estimate the changes in bikeshare usage during each reopening phase. It should be noted that the reopening phases varied across cities as a result of different policies being implemented.

The goal of this study was to analyze responses in relation to bikesharing behavior—usage and trip duration—during each pandemic phase to continue to gain knowledge and understanding of the postpandemic world. This study contributes to the literature by using the same methodology across multiple U.S. cities with varying reopening time frames and policies.

## Hypothesis Testing

During the pandemic, most businesses, activities, and services were suspended as a result of the restrictions, resulting in fewer commuting trips specifically and less bikeshare ridership generally. As the reopening phases progressed, these businesses, activities, and services recommenced and increased, although being required to reopen with limited occupancy and adhering to additional safety guidelines. Therefore, both member and nonmember ridership were anticipated to increase progressively throughout the reopening phases. Additionally, it was expected that trip durations would increase during the Lockdown period, and would decrease over the reopening phases, reverting to prepandemic levels. The hypotheses were grouped into two user types: member (HM) and nonmember (HN).

Hypothesis 1: Ridership increases again as the reopening phases progress.
HM-1. Member ridership increases as the reopening phases progress after Lockdown (and could decrease if restrictions are reinstated).
HN-1. Nonmember ridership increases as the reopening phases progress after Lockdown (and could decrease if restrictions are reinstated).
Hypothesis 2A: Median trip durations are not equivalent across reopening phases.
HM-2A. Member median trip durations vary across reopening phases.
HN-2A. Nonmember median trip durations vary across reopening phases.
Hypothesis 2B: Ridership is not equivalent across reopening phases.
HM-2B. Member ridership varies across reopening phases.
HN-2B. Nonmember ridership varies across reopening phases.

Wald tests were applied to the first hypothesis, and likelihood ratio tests were used to test the second at a 95% confidence interval across all five bikeshare systems to examine the significance of these hypotheses.

## Data Description

To examine the effects of the pandemic on the behavior of bikeshare users, five station-based bikeshare systems were selected across the United States: Capital Bikeshare (Washington, D.C.), Divvy (Chicago), Bluebikes (Boston), Nice Ride Minnesota (Minneapolis), and Metro Bike Share (Los Angeles). These five systems were chosen to reflect varying system sizes, geographical locations, weather, and operational characteristics. The first three systems were located in northern United States, featuring similar system sizes and running under similar weather conditions. Operationally different, Nice Ride Minnesota does not operate during winter because of Minneapolis's harsh weather—the system was therefore

**Table 1.** Summary of Bikeshare Systems

| System | Year | Total trips | Member trips | Nonmember trips |
|---|---|---|---|---|
| Capital Bikeshare | 2010–2020 | 28,271,662 | 22,077,242 | 6,194,420 |
| Divvy | 2013–2020 | 24,782,455 | 18,085,400 | 6,697,055 |
| Bluebikes | 2015–2020 | 10,036,297 | 7,768,822 | 2,267,475 |
| Nice Ride Minnesota | 2010–2020 | 3,692,567 | 1,947,052 | 1,745,515 |
| Metro Bike Share | 2017–2020 | 1,035,472 | 723,486 | 311,986 |

not operational as the pandemic began. Nice Ride Minnesota additionally varies in membership proportion with nearly equivalent member and nonmember trip volumes, whereas member trips dominate in the other systems. Metro Bike Share provided an example of a smaller sized bikeshare system that operated in a milder climate. By considering these five systems with diverse characteristics, the analysis sought to reveal examples of similar and varying bikeshare usage behavior.

Individual daily trip data were retrieved from each system's respective website (*21–25*) and consists of trip- and user information, including start and end time, start and end station, and user type. Owing to varying inception dates, the analysis period varied across the systems. The analysis periods and trip statistics are summarized in Table 1.

Trip rates are minimal at 4:00 a.m. compared with other times of the day. Therefore, daily trips were counted from the current day's low point to the next day's low point. Daily trips were aggregated by start time between 4:00 and 3:59 a.m. on the following day. The data were also aggregated into member and nonmember daily trip counts.

Finally, to control for weather conditions, weather data were retrieved from the National Oceanic and Atmospheric Administration and from Weather Underground databases (*26*, *27*). This analysis used data comprising maximum temperature, average wind speed, maximum dewpoint, snow depth, snowfall, and precipitation.

## Methodology

To examine the effects of the COVID-19 pandemic on the behavior of using bikeshare, this study focused on changes in the ridership and median trip duration with respect to rider membership status across five bikeshare systems in the United States. Several outliers related to trip duration were found during the exploratory data process. These outliers showed significantly high trip durations, which was unreasonable for a typical bike trip (e.g., people kept the bikes or returned them after several days). Because of the outliers, the difference between the range of daily median values and mean durations was large. For example, the highest differences between mean and median durations in Capital Bikeshare, Divvy, Bluebikes, Nice Ride, and Metro Bike Share were 129, 90, 1,417, 1,144, and 295 min, respectively. As a result, using the mean duration would have led to false inferences when interpreting the results. Therefore, this study chose the median duration to estimate the pandemic's effects on trip duration. In relation to membership status, both ridership and median trip duration were estimated for member and nonmember users across the five systems. Models were estimated by membership status because of the differences in bikeshare usage between user types. For example, it was expected that member users would be more likely to use bikeshare for commuting, and nonmember users would be more likely to use bikeshare for leisurely travel around the city. Therefore, estimating member and nonmember models separately would be expected to give insights into behavior change by trip purpose while using bikeshare during the pandemic. The heteroscedasticity in the time-series data was accounted for using Eicher–Huber–White robust standard errors when estimating the models.

### Median Trip Duration—Linear Regression

For estimating the changes in median trip duration from the effects of the pandemic, linear regression models with the following specification were estimated:

$$Trip_{median\ duration} = \beta_0 + \beta_T(Time) + \beta_P(Pandemic\ Factors) + \beta_W(Weather) \quad (1)$$

where
$\beta_0$ = constant,
$\beta_T$ = time factors,
$\beta_P$ = pandemic factors, and
$\beta_W$ = weather.

### Trip Volume—Log-linear Regression

Since daily trips for each system are highly affected by seasonal variations and temporal effects because of bikeshare system growth and varying demand over time, log-linear regression was applied when estimating trip volume using the following specification:

**Table 2.** Variable Description

| Variable | Description |
|---|---|
| Daily trips | Daily member/nonmember trips aggregated by the start time of 4:00 a.m. to the end time of 3:59 a.m. the next day. |
| Daily median trip durations | Daily member/nonmember median trip durations in minutes. |
| Year indicator | 1 if the year falls on one of the following: 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020; 0 otherwise. [10 indicators] |
| Month indicator | 1 if the month falls on one of the following: January, February, March, April, May, June, August, September, October, November, December; 0 otherwise. [11 indicators] |
| Day indicator | 1 if the day falls on one of the following: Monday, Tuesday, Thursday, Friday, Saturday, Sunday; 0 otherwise. [6 indicators] |
| First cases indicator | 1 if the day is in the First Cases period, 0 otherwise. |
| Lockdown indicator | 1 if the day is in the Lockdown period, 0 otherwise. |
| Phase 1 indicator | 1 if the day is in Phase 1, 0 otherwise. |
| Phase 2 indicator | 1 if the day is in Phase 2, 0 otherwise. |
| Phase 3 indicator | 1 if the day is in Phase 3, 0 otherwise. |
| Days since the last day of Lockdown | The number of days was counted from the last day of the (initial) Lockdown. |
| Snowfall | Snowfall in inches. |
| Snow depth | Depth of snow in inches. |
| Snow indicator | 1 if there was snowfall on that day, 0 otherwise. |
| Average wind speed | Average wind speed in miles per hour. |
| Maximum temperature | Maximum temperature in Fahrenheit. |
| Maximum dewpoint | Maximum dewpoint in Fahrenheit. |
| Rainfall indicator | 1 if there was rainfall on that day, 0 otherwise. |
| Precipitation from rain | Precipitation from rain, in inches. |

$$\log(trips) = \beta_0 + \beta_T(Time) + \beta_P(Pandemic\ Factors) + \beta_W(Weather) \quad (2)$$

Each model was estimated separately for member and nonmember trips. The variables for estimating the models are presented in Table 2.

The first year in each system and July were selected as the reference year and month, respectively. For the day of week fixed effects, Wednesday was the chosen reference. Five pandemic phases were analyzed in this study: First Cases, Lockdown, and Phases 1 through 3. First Cases occurred between the first reported local case and the initiation of a stay-at-home order. Lockdown occurred throughout the length of a region's stay-at-home order. For Phases 1 through 3, each phase's timing and meaning varied according to the regulations and time frames in each city, as summarized in Table 3. Generally, each progressive phase was more open, except for Phase 3 in Los Angeles, which was a reinstatement of the stay-at-home order.

## Descriptive Statistics

Across each system, both member and nonmember ridership increased annually except for 2020 (see Figures 1 and 2, respectively). Member trips dropped significantly in 2020 compared with the previous years. However, the seasonal effects were still clearly present in the bikeshare usage of members. Member ridership generally recovered after Lockdown as time progressed as more businesses and services reopened.

Conversely, nonmember ridership, in general, appeared not to be significantly affected by the pandemic (Figure 2). In the three largest systems analyzed, nonmember ridership was greater than in previous years. For Nice Ride Minnesota, nonmember trips showed similar decreases to that of member trips and less variability than the prior year.

These observations seem reasonable since member users were assumed to be more likely to undertake commuting trips, and nonmembers to be more likely to engage in leisure and recreation uses. Therefore, because of restrictions on activity and travel regulations, most work shifted to work-at-home, resulting in fewer commuting trips and thus fewer member trips. On the other hand, although leisure activity locations decreased (possibly temporarily), recreation may have increased since people may have seeked out shared bicycles to perform recreational trips, resulting in similar nonmember trip volumes.

In analyzing daily median trip duration, Figure 3 shows that member users generally made trips that lasted between 5 and 15 min. However, during 2020, these median trip durations increased compared with previous years. Similarly, nonmember users also made longer trips during 2020 (Figure 4). These increased durations could have been the result of roundtrips with single stops to pick up goods and to exercise during the pandemic. Data showed that travel times for nonmembers were generally

**Table 3.** Summary of Phases During the Pandemic in 2020

| System | First Cases | Lockdown | Phase 1 | Phase 2 | Phase 3 |
|---|---|---|---|---|---|
| Capital Bikeshare | 03/11–03/29: First cases of COVID-19 reported until the day before stay-at-home order instigated (no business restriction, schools closed) | 03/30–05/28: Stay-at-home order: individuals required to stay at home, but allowed essential business and travel, recreational activities | 05/29–06/21: Nonessential businesses allowed to reoperate with restrictions depending on type of business (e.g., services by appointment, pickup, and delivery only) | 06/22–12/31: Mass gatherings prohibited; nonessential businesses allowed to operate indoor services with limited occupancy; businesses and activities with high occupancy or close contact remained closed (e.g., bars, sports club, sauna, or hot tubs at gyms) | NA |
| Divvy | 03/09–03/20 (similar to Capital Bikeshare) | 03/21–04/30: Stay-at-home order: individuals required to work from home unless essential. Essential businesses allowed to open. Restaurants and bars allowed to operate pickup and delivery services | 05/01–06/02: Stay-at-home order partially relaxed: more retail stores, restaurants reopened, but order online and pickup only | 06/03–06/25: Cautious reopening: offices, salons, barbershops were reopened with limited occupancy | 06/26–12/31: Gradually resumed: school, childcare centers reopen, more business reopened, occupancy restrictions were lifted with appropriate safety guidelines |
| Bluebikes | 03/10–03/23 (similar to Capital Bikeshare) | 03/24–05/17: Stay-at-home order: individuals were required to stay at home except for essential travel and activities | 05/18–06/07: Nonessential business allowed to operate under safety guidelines. Recreation and outdoor activities opened with restrictions (e.g., beaches, parks, zoos) | 06/08–07/05: More businesses reopened with restrictions (e.g., retail stores, casinos, close contact services). Schools reopened for limited purposes. More recreation and outdoor/indoor activities reopened (e.g., golf, pools, camping) | 07/06–12/31: Businesses and activities with high occupancy and close quarters reopened with safety guidelines (e.g., movie theaters, museums, aquarium, weddings, sightseeing tours) |
| Nice Ride Minnesota | 03/13–03/24 (similar to Capital Bikeshare) | 03/25–05/17: Stay-at-home order: individuals required to stay at home except for essential needs | 05/18–06/01: Essential businesses able to maintain opening, nonessential businesses open with safety guidelines. Telework encouraged. Gatherings of people prohibited | 06/02–12/31: Close contact services, business, activities were allowed to reopen (e.g., restaurants, bars, barbershop) with limited occupancy or pickup and delivery only. Gyms, outdoor entertainment venues, activities allowed to reopen with limited occupancy. Social activities allowed to gather in up to 20 people | NA |
| Metro Bike Share | 03/04–03/18 (similar to Capital Bikeshare) | 03/19–05/07: Stay-at-home order: individuals were required to stay home except for maintaining operation of critical federal infrastructure. Essential workplaces were allowed to operate within safety guidelines | 05/08–06/11: Lower risk workplaces: reopening workplaces with low risk and safety guidelines. Retail reopened for pickup and delivery only. Essential offices reopened if telework not available | 06/12–11/20: Higher risk workplaces: reopening high-risk workplaces, businesses, activities with limited occupancy (e.g., high contact service, sports, movie theaters, religious services) | 11/21–12/31: Regional stay-at-home order: individuals were required to stay at home from 10 p.m. to 5 a.m. (owing to low availability of ICUs in county). Private parties and gatherings prohibited. Only critical infrastructure and retail allowed to open |

*Note*: ICU = intensive care unit, NA= not available.
The information about reopening phases was obtained from the reopening plans and guidelines of states/cities for each system (*28–32*).

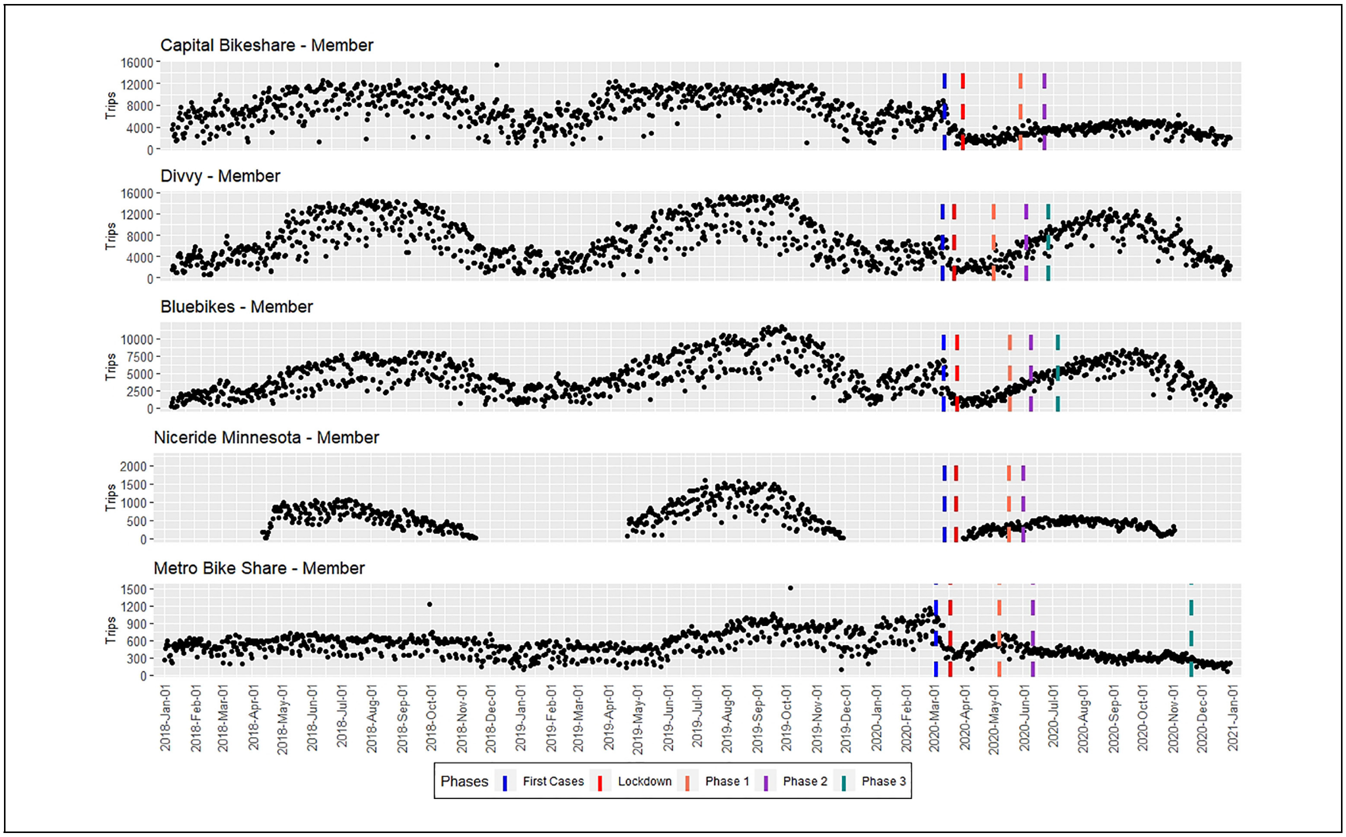


**Figure 1.** Member daily trips distribution (2018 to 2020).

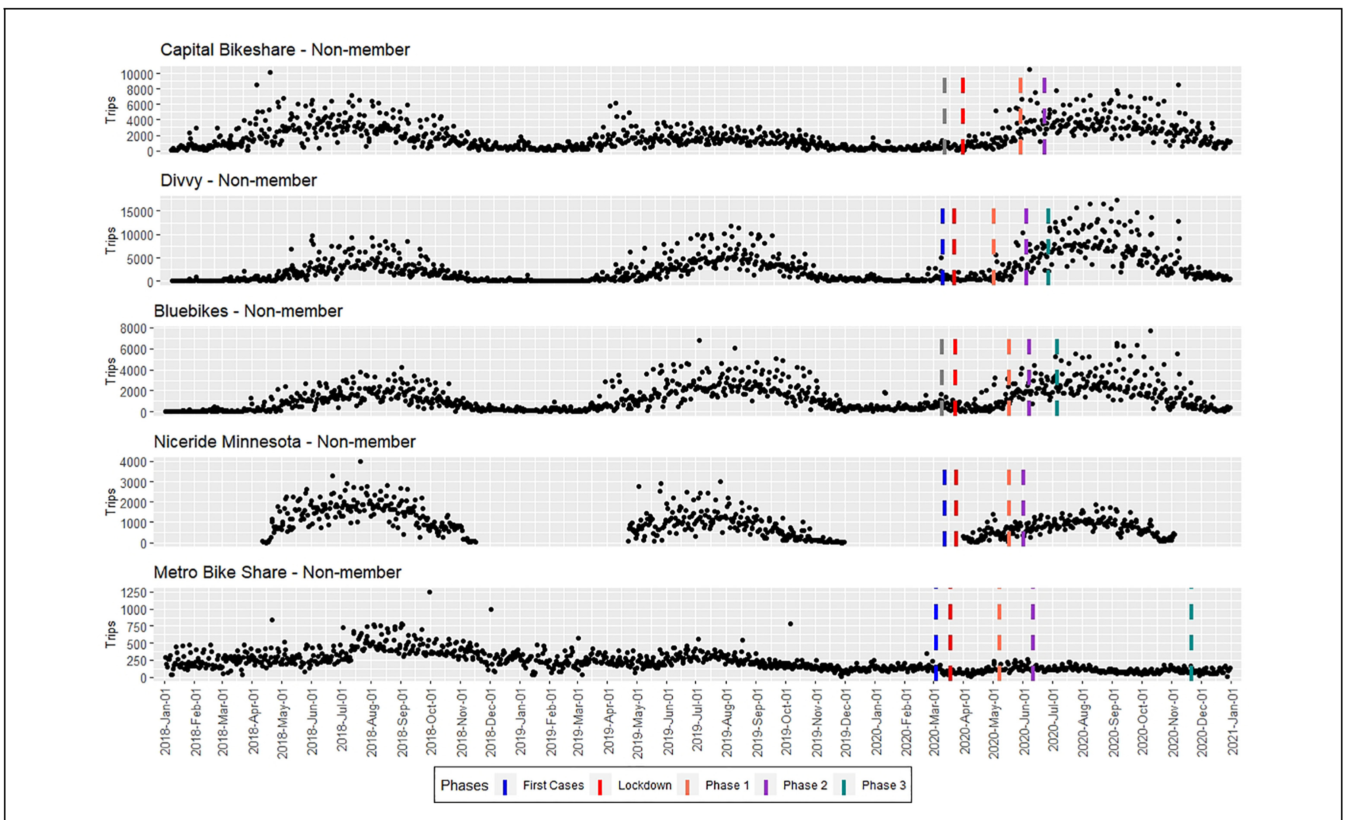


**Figure 2.** Nonmember daily trips distribution (2018 to 2020).

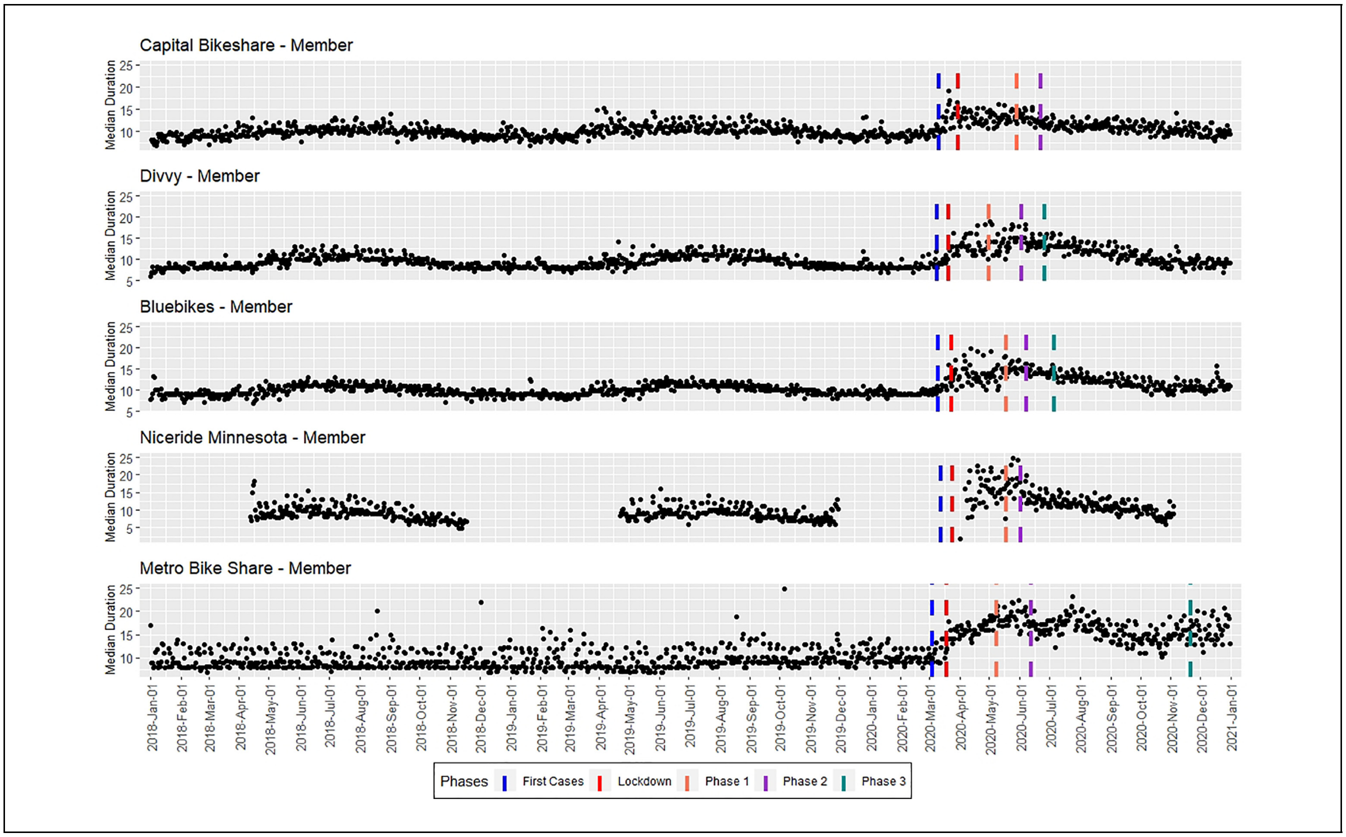


**Figure 3.** Member trips: daily median durations distribution (2018 to 2020).

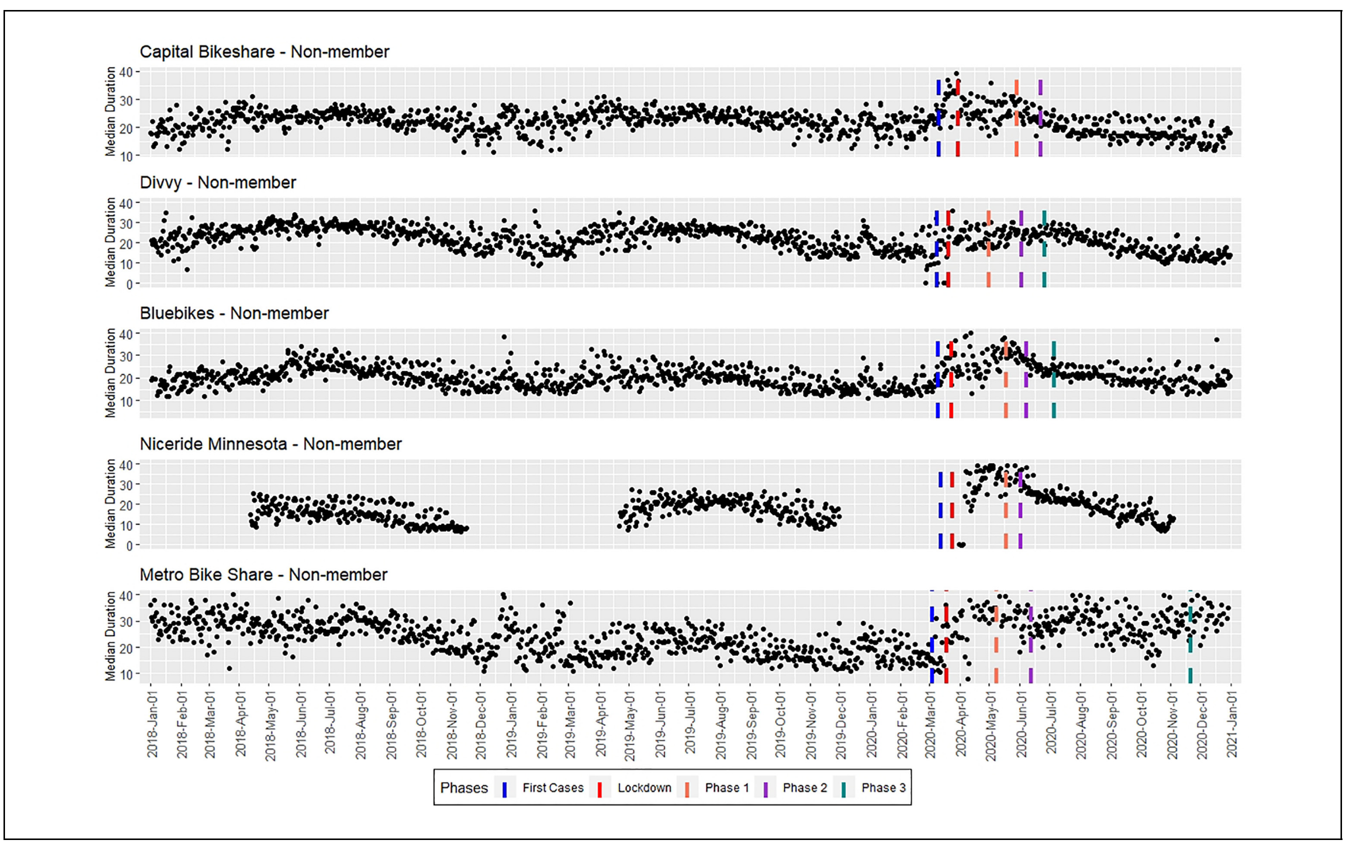


**Figure 4.** Nonmember trips: daily median durations distribution (2018 to 2020).

**Table 4.** Linear Regression Models Results of Member Median Trip Duration in Five Systems With Robust Standard Errors (in Minutes)

| Variable description | Capital Bikeshare (Washington, D.C.) | | Divvy (Chicago) | | Bluebikes (Boston) | | Nice Ride Minnesota (Minneapolis) | | Metro Bike Share (Los Angeles) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | *t*-stat | Mean | *t*-stat | Mean | *t*-stat | Mean | *t*-stat | Mean | *t*-stat |
| First cases indicator | 3.28 | 5.83 | 0.71 | 3.22 | 1.53 | 3.55 | na | na | 0.70 | 1.86 |
| Lockdown indicator | 2.73 | 18.54 | 3.86 | 15.76 | 3.40 | 12.23 | na | na | 5.45 | 15.67 |
| Phase 1 indicator | 2.53 | 12.72 | 4.35 | 13.72 | 3.12 | 13.16 | 2.64 | 2.65 | 7.16 | 14.22 |
| Phase 2 indicator | 1.07 | 7.65 | 3.69 | 14.49 | 1.93 | 10.82 | −2.60 | −3.62 | 3.86 | 4.18 |
| Phase 3 indicator | na | na | 2.51 | 11.31 | 0.29 | 1.18 | na | na | 6.42 | 11.58 |
| Days since the last day of Lockdown (÷ 100) | 0.00 | −3.18 | −1.06 | −8.49 | 0.03 | 0.18 | −2.15 | −5.49 | −1.25 | −3.78 |
| Number of observations | 3,750 | | 2,732 | | 2,185 | | 2,313 | | 1,397 | |
| $R^2$ | 0.7440 | | 0.8316 | | 0.6822 | | 0.4735 | | 0.7236 | |
| Adjusted $R^2$ | 0.7410 | | 0.8290 | | 0.6766 | | 0.4649 | | 0.7167 | |

*Note*: Year, month, day indicators and weather variables are not presented in this table, but were included in the model estimation.
na = not applicable.

greater than for members. This finding could support the assumption of bikeshare being used for leisure trips that have a lower value of travel time. To infer the pandemic's impacts on the bikeshare usage of member and nonmember users, the results of statistical models are discussed in the next section.

## Results

This section presents the results from the median trip duration models and total trip models. All models were estimated for both member and nonmember user types. To limit the impact of outlier trips (e.g., keeping bikes for several days before returning them), median trip duration was selected for model estimation instead of mean duration.

### *Member and Nonmember Median Trip Duration Models*

The pandemic variable estimates for the member median trip duration models are presented in Table 4. Throughout the pandemic, member riders tended to take longer trips, except for Nice Ride Minneapolis members during Phase 2. Changes in duration were generally decreasing throughout the pandemic for member users. For Capital Bikeshare, durations were similar during Lockdown and Phase 1, but decreased during Phase 2 (although remaining above prepandemic levels). The results showed that member riders of Capital Bikeshare made trips that were longer by nearly 3 min during Lockdown and Phase 1, but only 1-min longer during Phase 2. Divvy experienced increased durations during Phase 1 for members (i.e., 4.35-min longer), but trip durations decreased throughout reopening thereafter: 3.69 and 2.51-min longer in Phases 2 and 3, respectively. Bluebikes experienced progressive decreases in trip duration throughout reopening with a return to prepandemic levels in Phase 3. Compared with prepandemic levels, the results showed that member riders of Bluebikes made trips that were longer by 3, 2, and 1 min during Phases 1, 2, and 3, respectively. Similarly, Nice Ride showed increased trip durations during Phase 1, but shorter durations during Phase 2: 2.64-min longer and 2.60-min shorter in Phases 1 and 2, respectively. For Metro Bike Share, trip durations increased after Lockdown and began to decrease during Phase 2, but trip durations increased again during Phase 3 when Los Angeles reinstated a stay-at-home order.

The pandemic variable estimates for the nonmember median trip duration models are presented in Table 5. Nonmember users also generally took longer trips during the pandemic (with some exceptions). During the First Cases period, except in relation to Divvy, nonmember durations were observed to increase by 5.76, 6.37, and 2.69 min in Capital Bikeshare, Bluebikes, and Metro Bike Share, respectively. During Lockdown, nonmember users across all systems took trips that were longer by more than 3 min (5-min longer trip in Metro Bike Share). After Lockdown, Divvy did not show significant changes in durations across reopening phases, which were 3-min longer in all three reopening phases. Conversely, Bluebikes exhibited significantly decreasing durations throughout reopening compared with Lockdown: 9.55-min longer in Phase 1 and 3.36-min longer in Phase 2. Bluebikes' trip durations decreased to prepandemic levels during Boston's Phase 3 (fixed effect not significant). Similar to member durations, Nice Ride exhibited longer nonmember durations during Phase 1, by 6.13 min, and shorter durations during Phase 2, by 4.21 min, than in prepandemic levels. Capital Bikeshare reverted to prepandemic durations for nonmembers during Phase 1

**Table 5.** Linear Regression Models Results of Nonmember Median Trip Duration in Five Systems With Robust Standard Errors (in Minutes)

| | Capital Bikeshare (Washington, D.C.) | | Divvy (Chicago) | | Bluebikes (Boston) | | Nice Ride Minnesota (Minneapolis) | | Metro Bike Share (Los Angeles) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable description | Mean | *t*-stat | Mean | *t*-stat | Mean | *t*-stat | Mean | *t*-stat | Mean | *t*-stat |
| First cases indicator | 5.76 | 5.63 | −4.91 | −1.99 | 6.37 | 5.10 | na | na | 2.69 | 1.33 |
| Lockdown indicator | 2.49 | 5.50 | 3.60 | 4.58 | 11.27 | 13.95 | na | na | 15.13 | 9.52 |
| Phase 1 indicator | 0.63 | 1.60 | 3.47 | 5.06 | 9.55 | 13.19 | 6.13 | 3.57 | 15.43 | 7.86 |
| Phase 2 indicator | −2.80 | −6.53 | 3.23 | 4.99 | 3.36 | 5.71 | −4.21 | −2.72 | 1.72 | 0.68 |
| Phase 3 indicator | na | na | 3.56 | 5.03 | 0.95 | 1.46 | na | na | 5.60 | 3.53 |
| Days since the last day of Lockdown (÷ 100) | −0.01 | −2.68 | −3.65 | −10.96 | −0.14 | −0.32 | −7.56 | −13.55 | 3.93 | 4.51 |
| Number of observations | 3,749 | | 2,727 | | 2,178 | | 2,312 | | 1,397 | |
| $R^2$ | 0.6182 | | 0.6405 | | 0.7404 | | 0.6996 | | 0.4781 | |
| Adjusted $R^2$ | 0.6137 | | 0.6351 | | 0.7358 | | 0.6947 | | 0.4651 | |

*Note*: Year, month, day indicators and weather variables are not presented in this table, but were included in the model estimation.
na = not applicable.

with insignificant fixed effects, and decreased durations during Phase 2 (by 2.80 min) compared with prepandemic levels. Metro Bike Share nonmember users exhibited a slight increase in durations during Phase 1 compared with Lockdown, but significantly longer than prepandemic levels, by 15 min. Nonmember durations then decreased in Phase 2 with insignificant fixed effects, possibly to prepandemic levels. But Metro Bike Share nonmember durations significantly increased by 3.53 min compared with prepandemic levels when Los Angeles reinstated their stay-at-home order during Phase 3.

Accounting for pandemic fatigue (i.e. the state of being worn out by recommended precautions and restrictions relating to a pandemic), the "days since the last day of Lockdown" variable showed that both member and nonmember users generally made shorter trips over time, except for Bluebikes members and Metro Bike Share nonmembers. This could be the result of Los Angeles having a Lockdown during Phase 3. This aspect complicated the use of duration as a proxy of fatigue, and made its incorporation into the model nontrivial. The results indicated that, as the days since the last day of Lockdown increased by 1 day, member users made shorter trips by 0.001, 1.06, 2.15, and 1.25 min in Capital Bikeshare, Divvy, Nice Ride, and Metro Bike Share, respectively. Similarly, nonmember users made shorter trips by 0.01, 3.65, 0.14, and 7.56 min in Capital Bikeshare, Divvy, Bluebikes, and Nice Ride, respectively.

Moving to the fixed effects of the days of the week, the results showed clear patterns between weekdays and weekends for member trips. Generally, all weekdays had similar member trip durations. During weekends, member users made longer trips across the five systems than on weekdays. Members were more likely to undertake leisure activities or exercise during weekends, thus resulting in longer trips. Nonmember users made their shortest trips on Wednesdays, and longest trips on Saturdays, when controlling for all other factors.

In considering the impact of weather on trip duration, it was found that as average wind speeds and temperatures increased, all users were more likely to make shorter trips. Similarly, member and nonmember users made shorter trips on rainy days. Snowy days induced longer member trips, but shorter nonmember trips, which were anticipated because of differences in commute and leisure needs during snowstorms.

## Member and Nonmember Trip Models

Tables 6 and 7 present the pandemic variable estimates for the system-level daily trip ridership by membership type: member and nonmember, respectively. The results showed that during the First Cases period, lower ridership was observed among both members and nonmembers. A voluntary reduction in travel and contact occurred with people trying to avoid contracting COVID-19. Similarly, results showed less ridership for both member and nonmember users during Lockdown. The results indicated that ridership decreased by 78.56%, 71.92%, 86.87%, and 41.73% in Capital Bikeshare, Divvy, Bluebikes, and Metro Bike Share, respectively, during Lockdown. This finding could reflect how people traveled less during stay-at-home orders in all cities. As the reopening phases began, it was expected that ridership would rise again for both member and nonmember users. This was generally the case across all bikeshare systems, but ridership did not rebound to prepandemic levels except for Nice Ride Minnesota. Compared with prepandemic levels, it was found that ridership decreased by 69.88%, 66.71%, 83.14%, and

**Table 6.** Log-Linear Regression Models Results of Member Trips in Five Systems With Robust Standard Errors

| Variable description | Capital Bikeshare (Washington, D.C.) Mean | *t*-stat | Divvy (Chicago) Mean | *t*-stat | Bluebikes (Boston) Mean | *t*-stat | Nice Ride Minnesota (Minneapolis) Mean | *t*-stat | Metro Bike Share (Los Angeles) Mean | *t*-stat |
|---|---|---|---|---|---|---|---|---|---|---|
| First cases indicator | −0.74 | −6.60 | −0.52 | −3.58 | −0.87 | −6.59 | na | na | −0.14 | −1.75 |
| Lockdown indicator | −1.54 | −29.77 | −1.27 | −16.82 | −2.03 | −26.51 | na | na | −0.54 | −10.06 |
| Phase 1 indicator | −1.20 | −18.86 | −1.10 | −11.41 | −1.78 | −19.85 | 0.18 | 1.34 | −0.47 | −5.80 |
| Phase 2 indicator | −0.99 | −18.37 | −0.82 | −8.14 | −1.56 | −21.29 | 0.36 | 2.51 | −0.51 | −5.41 |
| Phase 3 indicator | na | na | −0.37 | −4.14 | −1.29 | −15.07 | na | na | −0.87 | −12.95 |
| Days since the last day of Lockdown (÷ 100) | 0.00 | 1.28 | −0.08 | −1.53 | 0.03 | 0.47 | 0.05 | 0.55 | −0.31 | −7.79 |
| Number of observations | 3,750 | | 2,732 | | 2,185 | | 2,313 | | 1,397 | |
| $R^2$ | 0.8249 | | 0.8250 | | 0.8572 | | 0.7841 | | 0.6981 | |
| Adjusted $R^2$ | 0.8229 | | 0.8223 | | 0.8547 | | 0.7806 | | 0.6906 | |

*Note*: Year, month, day indicators and weather variables are not presented in this table, but were included in the model estimation.
na = not applicable.

**Table 7.** Log-Linear Regression Models Results of Nonmember Trips in Five Systems With Robust Standard Errors

| Variable description | Capital Bikeshare (Washington, D.C.) Mean | *t*-stat | Divvy (Chicago) Mean | *t*-stat | Bluebikes (Boston) Mean | *t*-stat | Nice Ride Minnesota (Minneapolis) Mean | *t*-stat | Metro Bike Share (Los Angeles) Mean | *t*-stat |
|---|---|---|---|---|---|---|---|---|---|---|
| First cases indicator | −0.59 | −5.05 | −0.20 | −1.26 | −0.36 | −2.99 | na | na | −0.31 | −2.99 |
| Lockdown indicator | 0.01 | 0.11 | −1.02 | −9.74 | −1.36 | −13.23 | na | na | −0.60 | −7.72 |
| Phase 1 indicator | 0.79 | 11.14 | −0.97 | −9.96 | −0.96 | −9.56 | 0.01 | 0.05 | −0.04 | −0.70 |
| Phase 2 indicator | 0.71 | 9.18 | −1.04 | −11.07 | −0.98 | −12.21 | −0.31 | −2.92 | −0.19 | −2.40 |
| Phase 3 indicator | na | na | −0.94 | −10.59 | −0.87 | −8.81 | na | na | −0.71 | −8.43 |
| Days since the last day of Lockdown (÷ 100) | 0.00 | 6.21 | 0.63 | 13.75 | 0.06 | 0.81 | 0.56 | 6.73 | 0.05 | 0.95 |
| Number of observations | 3,749 | | 2,727 | | 2,178 | | 2,312 | | 1,397 | |
| $R^2$ | 0.8847 | | 0.9296 | | 0.8480 | | 0.8446 | | 0.7169 | |
| Adjusted $R^2$ | 0.8830 | | 0.9285 | | 0.8453 | | 0.8421 | | 0.7099 | |

*Note*: Year, month, day indicators and weather variables are not presented in this table, but were included in the model estimation.
na = not applicable.

37.50% in Capital Bikeshare, Bluebikes, Divvy, and Metro Bike Share, respectively, during Phase 1. Similarly, lower member ridership was observed during Phase 2: 62.84%, 55.96%, 78.99%, and 39.95% lower in Capital Bike Share, Divvy, Bluebikes, and Metro Bike Share, respectively. Additionally, it can be observed that Phase 3 for Metro Bike Share induced less ridership than Phase 2, which was around an 18.15% difference. This was expected as Los Angeles reinstituted a stay-at-home order toward the end of 2020.

For nonmember ridership, the reopening phases had mixed effects. Nonmember ridership significantly increased for Capital Bikeshare across their reopening phases, with 120.34% and 103.40% increases in Phases 1 and 2, respectively. However, Divvy showed no rebound effect with nearly equivalent ridership reductions during the Lockdown and across Chicago's three reopening phases: 62.09%, 64.65%, and 60.94% lower in nonmember ridership during Phases 1, 2, and 3, respectively. Bluebikes exhibited a slight rebound effect after Lockdown, but the effect was nearly constant across Boston's three reopening phases. For Nice Ride Minnesota, no reduction in nonmember trips was observed during Minneapolis's first reopening phase, but a subsequent decrease occurred during Phase 2 with a 26.66% drop in nonmember ridership. For Metro Bike Share, nonmember ridership fully rebounded initially, but decreased during Phase 2 and heavily decreased when Los Angeles reinstated its stay-at-home order with a 50.84% reduction in nonmember ridership during Phase 3.

Accounting for pandemic fatigue, the days since the last day of Lockdown variable had mixed effects on both member and nonmember users. As the pandemic continued, member ridership increased for Capital Bikeshare, but decreased for Metro Bike Share. For nonmember ridership, the results showed that Capital Bikeshare, Divvy, and Nice Ride Minnesota had higher ridership increases.

As the bikeshare systems have grown over the years, both member and nonmember trips have significantly increased. This finding is reasonable since the reference year in this study was the first year of each system. However, member and nonmember users exhibited opposing weekly temporal patterns. Member ridership was similar throughout the weekdays but decreased on weekends, whereas nonmembers had increased ridership over the weekend. Weather effects are generally reported in the literature with lower ridership as temperatures decrease, precipitation occurs and increases, and snowfall increases.

## Hypotheses Testing Results

Although there were three phases included in the stated hypotheses, some systems had only two phases (i.e., Capital Bikeshare, Bluebikes, and Nice Ride Minnesota) owing to their state or county regulations. Therefore, the hypotheses were tested from Phase 1 to the most current phase in the corresponding city. Additionally, it was expected that the transition from Phase 2 to Phase 3 for Metro Bike Share would have a contradictory relationship with $Ridership_{Phase2} > Ridership_{Phase3}$ forming an alternative hypothesis (because of an increase in restrictions). The hypothesis testing results are presented in Table 8.

For member ridership, HM-1 was supported at a 95% confidence level for Capital Bikeshare, Bluebikes, and Nice Ride. For Divvy, the hypothesis was supported at a 90% confidence level. This means that as the opening phases progressed, the number of member trips increased in these systems. This finding seems reasonable as increases in commuting would be likely to occur as more businesses opened after Lockdown. HM-1 was not supported for Metro Bike Share; it was found that trips decreased after increased restrictions were implemented in Phase 3 compared with Phase 2 trip volumes.

Moving to nonmember ridership, in general, the results did not support HN-1: increasing ridership over time across all five bikeshare systems. An increase was most likely during the first reopening phase compared with Lockdown, with this effect being observed for Capital Bikeshare, Bluebikes, and Metro Bike Share. Otherwise, nonmember ridership was not observed to decrease further as reopening continued. Ridership did decrease for Metro Bike Share after restrictions were increased during Los Angeles's Phase 3.

The results for trip duration generally supported HN-2A (i.e., that duration was not equivalent across Lockdown and all reopening phases) at a 95% confidence level. However, the relationship did not hold for Nice Ride Minnesota member trip durations or for Divvy nonmember trip durations. Support was however found for the nonequivalence of trip volumes throughout the pandemic for member trips, but support was more sporadic for nonmembers, with only Nice Ride Minnesota and Metro Bike Share observing significantly differing trip volumes throughout the pandemic.

## Conclusion

This study focused on examining the effects of the COVID-19 pandemic on bikeshare usage behavior with respect to membership across five bikeshare systems in the United States. By dividing the pandemic into phases, support was found for the hypotheses that assumed an attempted return to prepandemic normality as the pandemic progressed and regions progressively reopened. The study also found evidence of a reversion of behavior when restrictions were reinstituted. Specifically, both member and nonmember ridership were generally found to be significantly lower during the pandemic owing to the travel restrictions and closed businesses and suspended activities and services. Conversely, the results showed that both member and nonmember users made longer trips during the pandemic. This finding could reflect changes in the behavior of bikeshare users during the pandemic. For instance, they could have made longer trips for exercising and maintaining mental health since they were required to stay at home for long periods. Further study incorporating demographic, work status, and trip purpose information would allow for understanding the specific causes of this effect.

Because of restrictions during the pandemic, bikeshare ridership of both member and nonmember users tended to decrease significantly. However, bikeshare plays an important role in public health, so it is important for localities to maintain bikeshare services during times of activity disruption, such as the COVID-19 pandemic and natural disasters. This study found evidence of a shift in bikeshare usage between member and nonmember users during the pandemic. This shift was account for by working from home and casual users undertaking more cycling-related activity as alternate recreation during restricted times. This finding further suggests that operators of bikeshare systems may have missed an opportunity to increase ridership long-term and to maintain public health and well-being. Additionally, with the trend of significantly increasing nonmember ridership and slightly increasing member ridership, it was reasonably expected that the bikeshare systems would bounce back to prepandemic levels. Another interesting finding was the longer trip durations during the pandemic. This suggests that bikeshare was used for leisure trips or completing trips that would typically be done by other modes, such as transit or car. Therefore, the U.S. bikeshare system might be encouraged to focus on

**Table 8.** Hypothesis Testing Results

| Hypothesis | Test | Alternative hypothesis | Capital Bikeshare | Divvy | Bluebikes | Nice Ride Minnesota | Metro Bike Share |
|---|---|---|---|---|---|---|---|
| Member users | | | | | | | |
| HM-1 | One-sided Wald test of the equality of two coefficients | Lockdown ridership < Phase 1 ridership | **−4.49*** | −1.61 | **−2.54*** | — | −0.75 |
| | | Phase 1 ridership < Phase 2 ridership | **−2.98*** | **−2.27*** | **−2.50*** | **−1.86*** | 0.25 |
| | | Phase 2 ridership < Phase 3 ridership | — | **−4.40*** | **−3.78*** | — | — |
| | | Phase 2 ridership > Phase 3 ridership | — | — | — | — | **3.56*** |
| HM-2A | Likelihood ratio test | Median trip durations vary across reopening phases | **$\chi^2$ = 75.07* DF = 1** | **$\chi^2$ = 88.20* DF = 2** | **$\chi^2$ = 58.30* DF = 2** | **$\chi^2$ = 46.25* DF = 1** | **$\chi^2$ = 18.51* DF = 2** |
| HM-2B | Likelihood ratio test | Ridership varies across reopening phases | **$\chi^2$ = 8.02* DF = 1** | **$\chi^2$ = 44.56* DF = 2** | **$\chi^2$ = 15.78* DF = 2** | $\chi^2$ = 1.71 DF = 1 | **$\chi^2$ = 10.98* DF = 2** |
| Nonmember users | | | | | | | |
| HN-1 | One-sided Wald test of the equality of two coefficients | Lockdown ridership < Phase 1 ridership | **−9.52*** | −0.44 | **−3.38*** | — | **−7.04*** |
| | | Phase 1 ridership < Phase 2 ridership | 1.04 | 0.70 | 0.26 | 2.62 | 1.51 |
| | | Phase 2 ridership < Phase 3 ridership | — | −1.17 | −1.42 | — | — |
| | | Phase 2 ridership > Phase 3 ridership | — | — | — | — | **5.64*** |
| HN-2A | Likelihood ratio test | Median trip durations vary across reopening phases | **$\chi^2$ = 26.62* DF = 1** | $\chi^2$ = 0.18 DF = 2 | **$\chi^2$ = 72.24* DF = 2** | **$\chi^2$ = 115.77* DF = 1** | **$\chi^2$ = 20.99* DF = 2** |
| HN-2B | Likelihood ratio test | Ridership varies across reopening phases | $\chi^2$ = 0.51 DF = 1 | $\chi^2$ = 0.55 DF = 2 | $\chi^2$ = 0.54 DF = 2 | **$\chi^2$ = 4.86* DF = 1** | **$\chi^2$ = 30.09* DF = 2** |

*Note*: — denotes that a hypothesis test was not performed for this hypothesis and bikeshare system combination. DF = degrees of freedom. * and bolded entries indicate results at a 95% confidence level.

advertising campaigns to attract and raise bikeshare ridership as a pandemic progresses and subsides. City planners and policy makers might consider focusing on improving cycling infrastructure, guidelines, as well as policies to encourage more bikeshare usage or cycling activity in postpandemic times. Moreover, it would be interesting to see whether there will be a shift from driving cars or riding public transit to active modes, such as bicycling or walking postpandemic. Will nonmember users become members or even purchase their own bicycles? Will bikeshare ridership grow larger than prepandemic levels or revert back to a "normal" state? Future research and transportation professionals could explore such questions to further examine the impacts of COVID-19 on bikeshare usage, changes in travel needs, and travel behavior in postpandemic times.

One limitation of this study was that although it did find support for an attempt of reversion to prepandemic bikeshare behavior, but this analysis cannot guarantee postpandemic behavior will revert to prepandemic behavior across the systems analyzed. The causes of this could not be gleaned from this study because of limited user demographic data. An additional limitation was only including five study areas. Only bikeshare systems with publicly available data were included, four of which were among the five largest systems in the United States. Other bikeshare systems with different characteristics from these five systems would strengthen the results and give greater insights into bikeshare usage. Another limitation of this study was the lack of detail on system characteristics, such as the number of bicycles available, proportion of electric bikes, and the availability and quantity of e-scooters. With more systems analyzed and a pooled model structure, more exact effects of pandemic protocols could be explored, including the availability of businesses, services, and activities in each phase. Finally, autocorrelation was tested using the Durbin–Watson test; most systems did not have significant enough autocorrelation to require using autoregressive integrated moving average models, therefore, to simplify comparison, the authors analyzed all systems using the same model structure, but this could be relaxed in future studies.

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## Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: N. Barbour, M. Maness; data collection: L. Palaio, T. Vo; analysis and interpretation of results: T. Vo, M. Maness; draft manuscript preparation: T. Vo, N. Barbour, M. Maness. All authors reviewed the results and approved the final version of the manuscript.

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