


## Impact of COVID-19 on Public Transit Accessibility and Ridership

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### Abstract

COVID-19 has radically transformed urban travel behavior throughout the world. Agencies have had to provide adequate service while navigating a rapidly changing environment with reduced revenue. As COVID-19-related restrictions are lifted, transit agencies are concerned about their ability to adapt to changes in ridership behavior and public transit usage. To aid their becoming more adaptive to sudden or persistent shifts in ridership, we addressed three questions: To what degree has COVID-19 affected fixed-line public transit ridership and what is the relationship between reduced demand and -vehicle trips? How has COVID-19 changed ridership patterns and are they expected to persist after restrictions are lifted? Are there disparities in ridership changes across socioeconomic groups and mobility-impaired riders? Focusing on Nashville and Chattanooga, TN, ridership demand and vehicle trips were compared with anonymized mobile location data to study the relationship between mobility patterns and transit usage. Correlation analysis and multiple linear regression were used to investigate the relationship between socioeconomic indicators and changes in transit ridership, and an analysis of changes in paratransit demand before and during COVID-19. Ridership initially dropped by 66% and 65% over the first month of the pandemic for Nashville and Chattanooga, respectively. Cellular mobility patterns in Chattanooga indicated that foot traffic recovered to a greater degree than transit ridership between mid-April and the last week in June, 2020. Education-level had a statistically significant impact on changes in fixed-line bus transit, and the distribution of changes in demand for paratransit services were similar to those of fixed-line bus transit.

### Keywords

data and data science, urban transportation data and information systems, data analysis, public transportation, bus transit systems, public transportation

The novel coronavirus, COVID-19, has radically transformed travel behavior in urban areas throughout the world. Although COVID-19 has affected normal operations in almost all industries, the social distancing measures and precautions associated with this virus have had particularly devastating effects on public transit. For instance, since the World Health Organization declared COVID-19 a pandemic on March 11, 2020 (1) subway ridership in New York City dropped by upwards of 91% (2). Given that public transit was already operating at a loss before COVID-19 (3), this disruption has created pressing operational challenges for public transit agencies.

First and foremost, agencies must determine how to continue providing adequate service while navigating a rapidly changing environment with reduced revenues. Even as COVID-19-related restrictions are lifted, transit agencies are increasingly concerned that the systemic

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shock of COVID-19 has caused fundamental changes in ridership behavior and public transit usage. There is no guarantee that revenues will return to pre-COVID levels; the pandemic accelerated remote and hybrid work options, rendering transit agencies unsure whether traditional assumptions about transit behavior still hold.

Faced with drastic drops in revenue, transit agencies rapidly reduced vehicle trips to keep costs under control. However, a reduction in transit accessibility disproportionately affects populations who are already disadvantaged, including lower-income populations who cannot afford personal vehicles (4) or people with disabilities. As lower-income populations are more likely to rely on the public transit system to get to work, school, or to access child services, agencies must take care when identifying transit vehicle trips to cut to avoid hurting those most reliant on local transit services.

Mobility-impaired transit users are often overlooked and must be taken into account in future planning. According to the U.S. Census Bureau, in 2014 nearly one in three adults 18 years and older had a disability, one in five had a severe disability and one in ten had a disability that required assistance (5). These users are often reliant on paratransit services, that is, a supplement to fixed-route services provided by transit agencies to ensure equity for disabled people. Providing adequate access to paratransit is of critical societal importance, and although it is expensive, the societal benefits of a robust paratransit system far exceed its cost (6). As current research continues to provide insights into the impact of COVID-19 on various transit modes, there has been a negligible focus on changes in demand for paratransit services.

Focusing on Nashville and Chattanooga, TN, we were primarily concerned with the following questions: First, to what degree has the COVID-19 pandemic affected ridership of fixed-line public transit and what is the relationship between reduced demand and reduced vehicle trips? Second, how has COVID-19 changed ridership patterns and are these changes expected to persist after restrictions are lifted? Although this is impossible to know for certain, we provide a spatiotemporal analysis of bus ridership decline to generalize broad changes in ridership patterns. We also compared ridership declines to anonymized mobile location data to identify whether public transit users have switched to personal vehicles. Third, are there disparities in ridership changes across socioeconomic groups and among mobility-impaired users? For this we employed a correlation analysis and explanatory linear model to investigate the relationship between socioeconomic indicators and the drop in transit ridership. We also analyzed changes in paratransit demand before and during COVID-19.

Ultimately, the investigative analysis provided in this work aims to be a starting point for transit agencies to

become more adaptive to sudden or persistent shifts in ridership behavior. Therefore, we highlight the importance of modeling the socioeconomics of ridership behavior so that transit agencies can reduce or expand vehicle trips such that those most reliant on public transit and paratransit services have adequate access. In this way, transit agencies can be better informed about their own operations and can plan for future events accordingly.

## Contributions and Key Findings

The primary contributions of this work are as follows:

1. We outline the operational changes Nashville and Chattanooga imposed following the start of the COVID-19 pandemic. We found that ridership declines were largely uncorrelated with changes in the number of vehicle runs in both cities.
2. We provide a summary of ridership changes resulting from COVID-19 in both cities. We found that ridership initially dropped by 66% and 65% over the first month of the pandemic for Nashville and Chattanooga, respectively, before starting a moderate recovery and stabilizing 3 months later.
3. A temporal investigation of ridership before and during COVID-19 showed an outsized proportion of changes in ridership occurred on weekdays during the morning and evening peak hours, indicating a potential persistent shift toward alternative work options or possibly a shift to personal vehicles for commuters. Cellular mobility patterns in Chattanooga indicated that foot traffic recovered to a greater degree than transit ridership between mid-April and the last week in June, 2020.
4. Our spatial analysis indicated that changes in ridership varied greatly across census tracts and neighborhoods. We found that ridership declined up to 19% more in high-income neighborhoods than in the lowest-income areas of Nashville. Additionally, our models showed that education level had a statistically significant impact on change in ridership at the aggregate level (per census tract).
5. We performed a temporal investigation of ridership before and during COVID-19 for paratransit services in Nashville and found that the distribution of changes in demand were similar to the findings of our analysis of fixed-line bus transit.

The remainder of this article is as structured follows. First, we summarize recent literature on socioeconomic transportation studies and the impact of COVID-19 on

public transit systems. We then describe the data and processing methods employed, followed by our analysis and results. Finally, we summarize our key findings, present the implications of this work for transit agencies, and discuss possible limitations of this study.

## Related Work

In this section we cover literature related to COVID-19 in the context of transportation systems and the interaction of socioeconomics and transit usage.

### COVID-19 and Transportation

Fixed-line bus and rail public transit inherently involves moving passengers in an enclosed space. One of the major reasons there has been a significant decline in public transit ridership recently is the fear of contracting COVID-19. Infectious disease transmission through public transit and air travel has been widely studied in health-related fields (7–10). Although there is a growing body of publications on the spread of COVID-19 by air travel (11), there is a lack of information on how this might apply to public transit (12). Regardless of disease transmission rates on public transit, ridership on fixed-line bus transit has declined significantly, as we show in this work.

Recent work on the impact of COVID-19 on urban transportation shows that decreases in public transport ridership range from 40% to 80% for bus systems throughout Europe and the United States (13–15). A study in New York showed that average subway and commuter rail ridership was down 80% whereas bus ridership was down 50% in the first week of July, 2020 with a peak subway ridership decline of 94% in late March (2, 16). There has been work showing that the types of tickets sold have changed as well. In Sweden, riders mostly switched from monthly tickets to single tickets and travel funds. Furthermore, tickets typically used by tourists dropped to almost zero, showing that the way in which riders interact with fixed-line transit has changed (13).

Recent work has investigated the mode shift away from public transit (17). Although modeling of the lasting effects of the pandemic is in its early stages, in some high-transit ridership cities even moderate shifts from public transit to personal vehicles can increase travel times by 5 to 10 min on average for one-way trips (17). However, in New York City the bike sharing program, CitiBike, has been more resilient to losses in ridership than the subway system and there is some evidence of transit users shifting to shared bike programs (18).

### Socioeconomics and Equity in Transportation

Previous research indicates different transit behaviors among socioeconomic classes. When it comes to public transit, low-income and historically marginalized groups are particularly reliant on public transportation (19). In this context, low-income groups are more likely to ride buses whereas high-income individuals are more likely to utilize rail systems (20). According to a 2017 publication from the American Public Transportation Association, 30% of bus riders have a household income of less than \$15,000, whereas 12% of bus riders have a household income of \$100,000 or more. Among rail riders only 13% have household incomes below \$15,000, whereas 29% have household incomes of \$100,000 or more (21).

A study conducted in Hawaii of public transit versus privately owned mobility options reported key differences between bus riders and solo car drivers: the mean household income of a bus rider was 16% lower than that of a solo driver (22). Bus riders also, on average, owned fewer cars per household (1.7 cars) compared with solo drivers (2.3 cars) (22). A major reason low-income groups are heavily reliant on public transportation is their lower likelihood of owning a personal vehicle. According to an analysis of 2012 California Household Travel Survey data, economic or physical barriers were reasons 78% of households did not own a car (4). Together, these studies suggest that individuals of a lower socioeconomic background may be disproportionately affected by changes in public transit availability. It is important to note that these trends are not unique to the United States; a case study conducted in France found that low-income individuals comprised a larger portion of public transit ridership than high-income individuals (23).

The magnitude of discrepancies between mode choice and socioeconomic background is not uniform when comparing the transit systems of different urban centers (19). In a study of mode choice by income level in Atlanta, Los Angeles, and New York, research showed that bus riders in Atlanta and Los Angeles were disproportionately on low incomes, however, these findings were not mirrored in New York (19). Additionally, whereas bus riders were disproportionately African American and Hispanic in both Atlanta and Los Angeles, the mode-choice demographics in New York mirrored those of the urban population generally (19). This indicates that the relationship between income level, demographics, and mode choice is dependent on the mode choices available and the equity of the underlying transit system. It is therefore important for transit agencies to monitor ridership dynamics and changes over time to make informed decisions that promote equity. This becomes critical when faced with drastic, sudden shifts in ridership behavior, as in the case of COVID-19 restrictions.

**Table 1.** Boarding Counts Before and After Processing and Number of Census Tracts for Nashville and Chattanooga Datasets

	Raw boardings (2020 YTD)	Processed boardings (2020 YTD)	Number of census tracts
Nashville	2,800,000	2,800,000	120
Chattanooga	464,570	445,987	82

Note: YTD = January 1, 2020 to July 1, 2020.

Provision of paratransit is critical for mobility-impaired users. Paratransit is demand-responsive in that trips are requested from users ahead of time and aims to bridge accessibility gaps in public transit. One example of a gap in accessibility is subway or bus stops that are not wheelchair accessible. In New York for instance, 55% of the population uses public transit to travel to work, however only 20% of subway stations are wheelchair accessible (24). Research indicates that the total benefits of paratransit to society far exceed its costs (6).

### Research Gaps

Although socioeconomics and equity have been widely studied in relation to public transit operations, there has been limited work on how COVID-19 has affected these dynamics. We aimed to address this both from the viewpoint of demand and supply. For demand we attempted to understand the relationship between socioeconomics and public transit ridership. For supply, we investigated reductions in vehicle trips. Despite its importance, to the best of our knowledge, the impact of COVID-19 and the sudden shifts in user demand have not been studied in the context of paratransit services.

### Data Collection and Processing

In this section, we outline the datasets used in this work, which consist of transit- and paratransit ridership boarding information, economic data per census tract, and COVID-19 cases per day. We also describe the data processing and filtering methods employed.

#### Ridership and Paratransit Data

Boarding count data were provided by the Nashville Metropolitan Transit Authority (MTA) for their fixed-line bus system from January 1, 2019 to July 1, 2020. Boarding data were also acquired from the Chattanooga Area Regional Transportation Agency (CARTA) for the period January 1 to July 1, 2020. The ridership data were derived from the farebox units on all passenger vehicle servicing trips within these time ranges. The farebox data included a record of every passenger boarding event.

They also included driver information, a unique vehicle identifier, data on shift changes, and when vehicles switched routes. The farebox data did not, however, include alighting information. The farebox data were filtered so that only boarding events remained. In 2020 there were 2.8 million documented boardings in Nashville between January 1 and July 1, 2020; for Chattanooga there were 465,000 documented boardings between January 1 and July 1, 2020. Each row in the respective datasets corresponded to a single boarding event.

As complete data were available for Nashville in 2019 we derived baseline ridership metrics by comparing weekly data in 2020 directly to the corresponding week in 2019. Additionally, the full 2019 data provided GPS locations, which allowed for spatial comparisons to baseline ridership. For Chattanooga we were provided with aggregated monthly total boardings for 2019. For baseline calculations related to Chattanooga we compared each week in 2020 with the mean ridership per week in the corresponding month from 2019. For Nashville, the GPS location of the vehicle at the time of boarding was available for each boarding event. However for Chattanooga, there were significant missing GPS readings. Therefore, to add GPS locations to these data we joined the ridership data with a separate telemetry dataset from onboard devices provided by ViriCiti (25), which included GPS readings and unique identifiers. For each boarding event we used the unique vehicle identifier in the farebox data to find the nearest GPS reading in the ViriCiti dataset. We filtered out boarding events that did not have a GPS reading within a 60-s window of the boarding event. After this process, approximately 4% of ridership boardings were removed from the Chattanooga ridership dataset. Once the ridership datasets were prepared, we used the GPS location of each boarding event to assign that event to a 2010 census tract. An overview of the total number of boardings, boardings after processing, and the number of census tracts in both cities is provided in Table 1.

Paratransit data were provided by Nashville MTA for a 2-week period from on April 28 to May 11, 2020 as well as from April 26 to May 9, 2019. There were a total of 16,490 passenger trips in the 2019 dataset and 5,578 passenger trips in the 2020 dataset.

### ***Economic Data, Cellular Mobility Data, and COVID-19 New Case Counts***

Economic data were retrieved from the U.S. Census Bureau (26) and ProximityOne (27). These sources provided a breakdown of the racial demographics, income levels, and housing information of residents in each of the 2010 census tracts. We additionally accessed Longitudinal Employer-Household Dynamics data (28) to extract workplace demographic data from the LEHD Origin-Destination Employment Statistics (LODES) dataset. The LODES data provided socioeconomic information on workers employed by census tract. This included the number of workers in a census tract that were White, African American, or Hispanic as well as the number of workers with or without a college degree, and the number of jobs in various fields such as education, entertainment, and food services. In this case, if a person holding a college degree lives in census tract  $i$  but works in census tract  $j$ , the socioeconomic indicators of this job would be attributed to census tract  $j$  in the LODES dataset. In this work, we refer to socioeconomic indicators in census tract  $i$  as “residence” indicators, and socioeconomic indicators in census tract  $j$  as “workplace” indicators.

Anonymized mobile location data were acquired from SafeGraph (29) for Hamilton County (including Chattanooga) from January 1 through July 1, 2020. The mobility data included 4,812 places of interest (POIs) throughout the region, 4,800 of which were within CARTA’s operational boundary. Each POI included the number of unique visitors per day and the latitude and longitude of the POI. This dataset was used to represent mobility patterns within the Chattanooga region. New COVID-19 cases per day for Nashville and Chattanooga were additionally retrieved from *The New York Times* COVID-19 dashboard (30) between January 1 and July 1, 2020.

### ***Mapping Boarding Events to Census Tracts***

To incorporate census-tract-level economic data, each boarding event was mapped to the corresponding census tract where that boarding occurred. As each census tract included a geometric polygon representing the tract this required a simple spatial join. One limitation of working with aggregated 2019 data for Chattanooga was that we were not able to access baseline ridership information at the census tract level, however, these data were available for Nashville.

### **Analysis and Results**

In this section we outline the main analyses and results for this work. We start by giving a high-level overview of

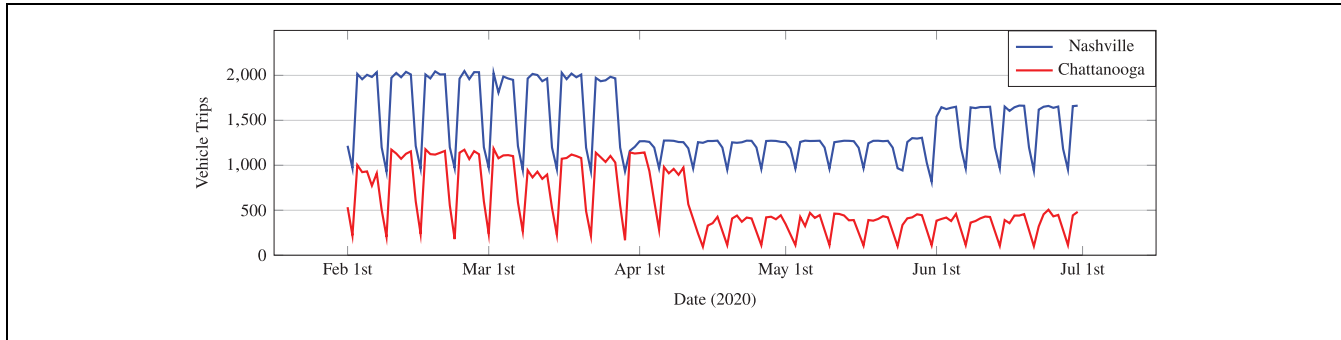
the COVID-19 restrictions and the corresponding operational changes implemented by the transit agencies in Nashville and Chattanooga, before moving onto our analysis of ridership declines in both cities. We then present a socioeconomic analysis and associated models. Finally, we present our findings related to paratransit operations.

### ***COVID-19 Restrictions and Operational Changes***

Nashville and Chattanooga both received guidance about COVID-19-related restrictions directly from Tennessee State Government. Both cities were able to impose their own regulations beyond those of the state’s recommendations. On March 5, 2020 the first COVID-19 case was identified in Tennessee and on March 8, 2020 the first COVID-19 case was found in Nashville. The Tennessee State Government ordered a state of emergency with regard to the pandemic on March 12, 2020 and the “Safer at Home” Executive Order on March 30, 2020 that mandated residents to stay in their homes other than for “essential activities.” The Tennessee Safer at Home order ended on April 30, 2020 (31).

Nashville regulations were more swift. Nashville imposed their own Stay at Home Executive Order on March 22, 2020, which was not lifted until Phase 1 reopening began on May 11, 2020. The Phase 1 reopening in Nashville allowed gatherings of up to 10 people, and most businesses were allowed to open at 50% capacity. On May 25, 2020 Nashville moved to Phase 2, which allowed gatherings of up to 25 people and most businesses could operate at 75% capacity (32). Nashville moved to a Phase 3 reopening on June 20, 2020, which included provisions for a limited reopening of small venues (up to 250 people); however, this reverted back to a Phase 2 reopening on July 3, 2020.

Both Nashville and Chattanooga reduced the total number of vehicle runs in reaction to the initial reduced demand at the start of COVID-19. However, unique trip identifiers were not available in either dataset. Therefore, to tally the number vehicle trips serviced per week we grouped the data by date, unique driver ID, unique vehicle ID, route, and direction. Daily vehicle trips for Nashville and Chattanooga are shown in Figure 1. Chattanooga moved to a reduced bus schedule in mid-April whereas Nashville switched to a reduced schedule on March 29, 2020. Before the schedule change, Chattanooga serviced an average of 6,100 vehicle trips per week. During the week of April 19, 2020 Chattanooga switched all weekdays to their Saturday schedule, which reduced the average weekly number of vehicle trips to 2,600, a decline of approximately 57%. Nashville switched to a reduced schedule during the



**Figure 1.** Daily vehicle trips for Nashville and Chattanooga from February 1 to July 1, 2020.

week of April 1, 2020. Before switching, Nashville serviced an average of 12,206 weekly vehicle trips, which was reduced to an average of 8,324 weekly vehicle trips from the week of April 5 to the week of May 24, 2020 which was a 31% reduction in vehicle trips. Starting in June, Nashville increased the number of vehicle trips to an average of 10,358 trips per week, a 17% reduction from pre-COVID operations.

### Impact of COVID-19 on Citywide Ridership

The fundamental questions addressed in this section are, from a global, system-level perspective, to what degree has COVID-19 decreased ridership? And to what degree can these changes be attributed to changes in demand versus changes in supply? Figure 2, *a* and *b*, shows weekly total ridership and weekly new COVID-19 cases in Nashville and Chattanooga, respectively. Figure 2*c* shows the drop in ridership for Nashville and Chattanooga compared with their 2019 baselines.

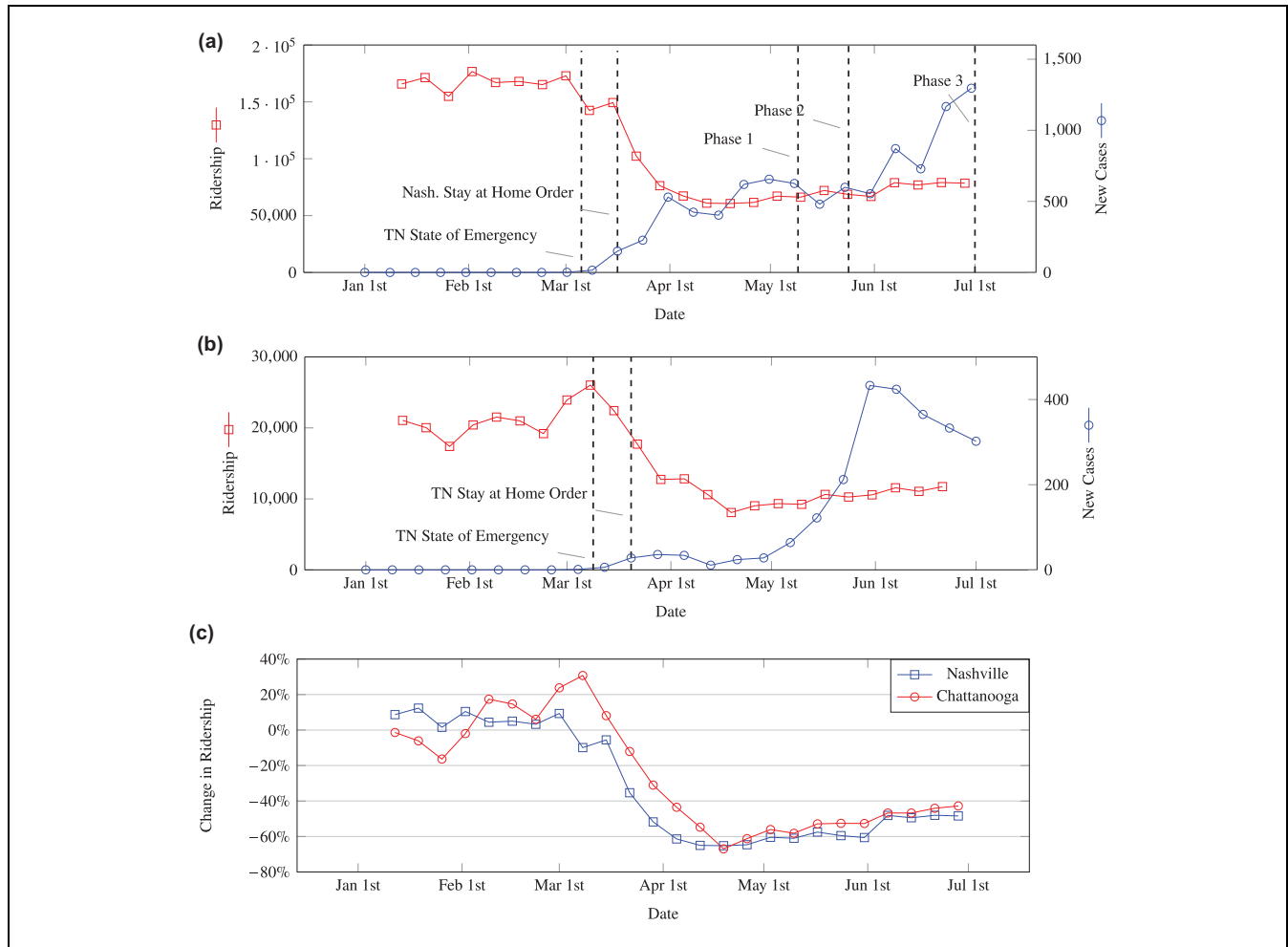
As shown in Figure 2*a*, Nashville public transit ridership started to decline on the week of March 1, 2020, which corresponded with the first known COVID-19 case in Tennessee (March 5), and the Tennessee state of emergency order on March 12. Perhaps more importantly, there was a major tornado in Nashville on March 3, 2020 (33) which helps to explain the initial decline in ridership at this time. Ridership remained constant for a week before a significant decline started during the week of March 22, 2020 when the Nashville Safer at Home order came onto effect. Nashville reached a low of 60,620 riders during the week of April 19, 2020, which was a 66% reduction in ridership compared with the 2019 baseline, as shown in Figure 2*c*. Ridership then stabilized, and by the week of June 28, 2020 ridership in Nashville had recovered 22% from the low in April, 2020. Chattanooga's steep decline started the week of March 5, 2020 before hitting a low (also on the week of April 19, 2020) of 8,077 weekly riders, representing a 65% loss in ridership compared with the 2019 baseline.

Chattanooga ridership recovered to 11,725 riders in the week of June 28, 2020, which was an increase of 45% from the low in April, 2020.

Both cities saw a rapid decline in fixed-line bus ridership from early March to late April, 2020 before ridership stabilized through the end of June of that year. In both cases, the initial rapid decline in ridership occurred well before vehicle trips were reduced in either city. The magnitude of ridership decline in both cities was similar at the same stage, despite Nashville and Chattanooga cutting vehicle trips by differing amounts: Chattanooga reduced the total number of vehicle runs by 57% following the start of COVID-19 and Nashville initially reduced the total number of vehicle runs by only 31%. Even though Nashville added capacity in early June, 2020 both cities stabilized at similar ridership declines through the remainder of the month. Therefore, in these two cities ridership decline was most likely driven by low demand.

### Route-Level Investigation

Figure 3, *a* and *b*, shows the monthly ridership distribution for the top five routes for the cities of Nashville and Chattanooga, respectively. In these we saw similar trends to the aggregated ridership analysis described in the previous section. In both cities, ridership decreased rapidly before stabilizing in April, 2020. In Nashville however, a greater rebound was observed between April and June 2020 than in Chattanooga. The rebound in Nashville corresponded loosely with the Phase 2 reopening. An important note is that Route 14 in Chattanooga is one of the most used routes, however, it is unique in that it is a free shuttle service to the University of Tennessee, Chattanooga. When university teaching went online in March 2020, Route 14 initially continued operating its regular Saturday schedule. However, owing to the drastic demand reduction during this time, Chattanooga ultimately stopped the service entirely on April 5, 2020. The most populated routes were observed to follow a similar trajectory and magnitude of ridership drop as the fixed-



**Figure 2.** Weekly ridership and new COVID-19 cases per week: (a) Nashville and (b) Chattanooga. (c) Change in ridership compared with 2019 baselines for Nashville and Chattanooga from January 1 through July 1, 2020.  
 Note: TN = Tennessee; Nash. = Nashville.

line transit system overall. Therefore, a more detailed spatiotemporal analysis is outlined in the following sections of this paper.

**Spatiotemporal Analysis of Transit Usage and Rider Behavior**

We investigated spatiotemporal changes in ridership between pre- and mid-COVID operations. For both cities normal operations spanned from January 1 to the end of February 2020 and, after a rapid drop in ridership, stabilized in mid-to-late April 2020. Therefore we used January to February to represent pre-COVID operations and May to June to represent mid-COVID operations. In Figure 4, a and b, the ridership distribution of Nashville and Chattanooga for each day of the week for pre- and mid-COVID operations are illustrated. In both cities, the drop in ridership at the weekend was less than on weekdays, with Chattanooga only seeing a 20%

decrease in ridership on Saturdays and a 32% decrease on Sundays compared with an average of 56% on weekdays. Nashville saw a 41% decrease in ridership on Saturdays and a 47% decrease on Sundays compared with an average decrease of 57% for the weekdays.

Figure 5, a and b, shows ridership pre-COVID compared with ridership mid-COVID per hour of the day. The biggest drops in ridership occurred during the morning- and evening peak. This is highlighted in Nashville where the morning peak (5:00 to 9:00 a.m.) saw a 64% change in ridership and the evening peak (3:00 to 6:00 p.m.) saw a 62% decrease compared with a 42% change between 9:00 a.m. and 3:00 p.m. This discrepancy was not as pronounced in Chattanooga where there was a 62% and 56% decrease in ridership for the morning and evening peak, respectively, compared with a 53% decrease between 9:00 a.m. and 3:00 p.m.

Figure 6 shows weekly transit ridership compared with visits to POIs from anonymized mobile location

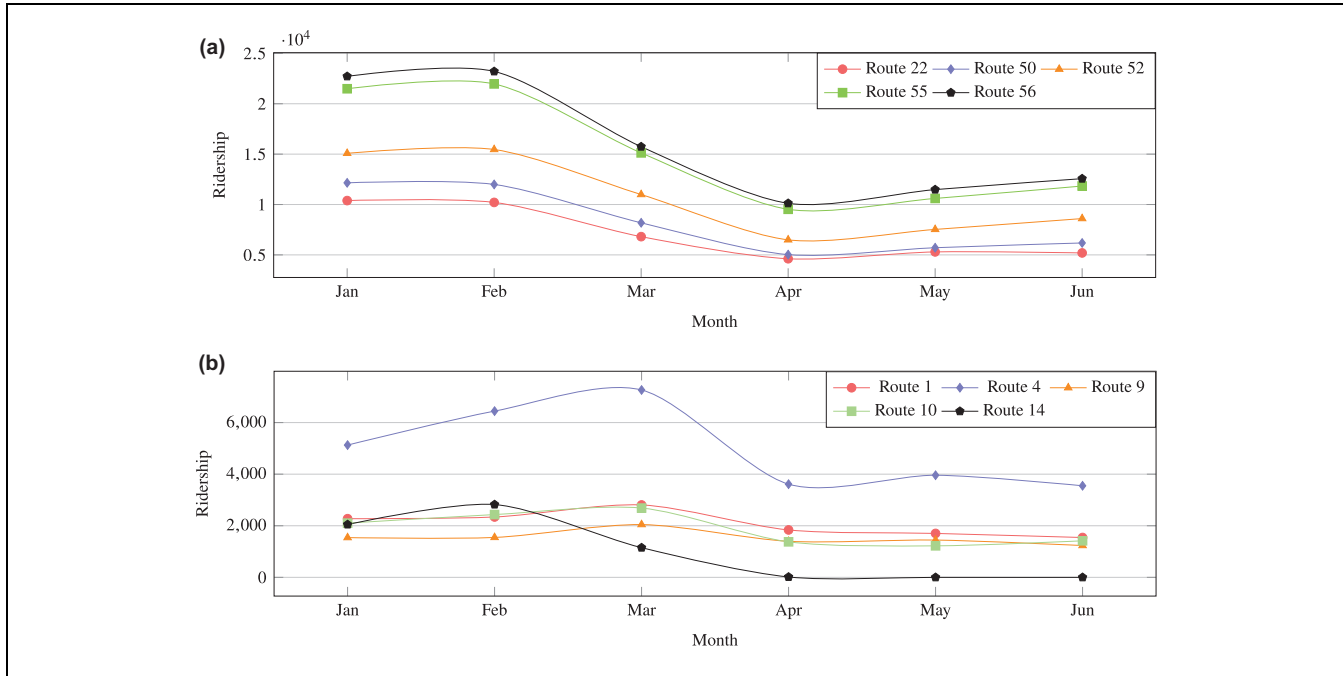


Figure 3. Ridership by month for the five most popular routes in (a) Nashville and (b) Chattanooga in 2020.

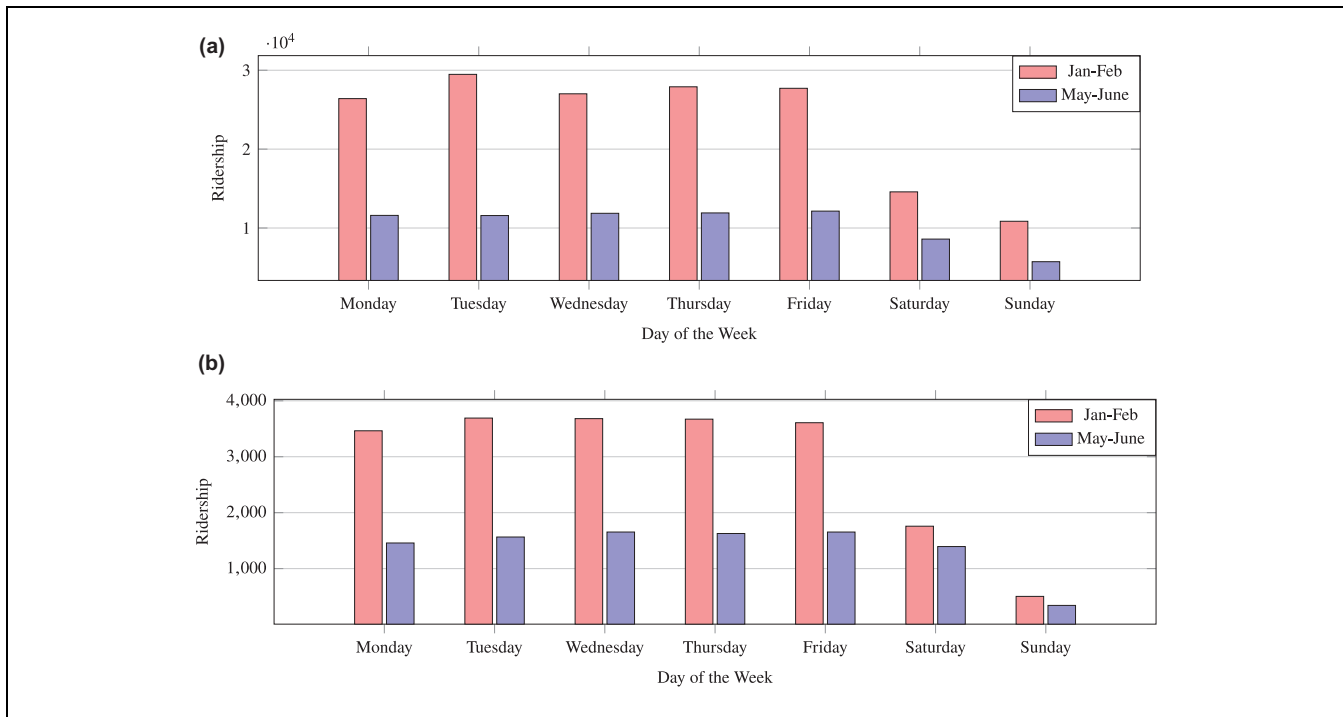
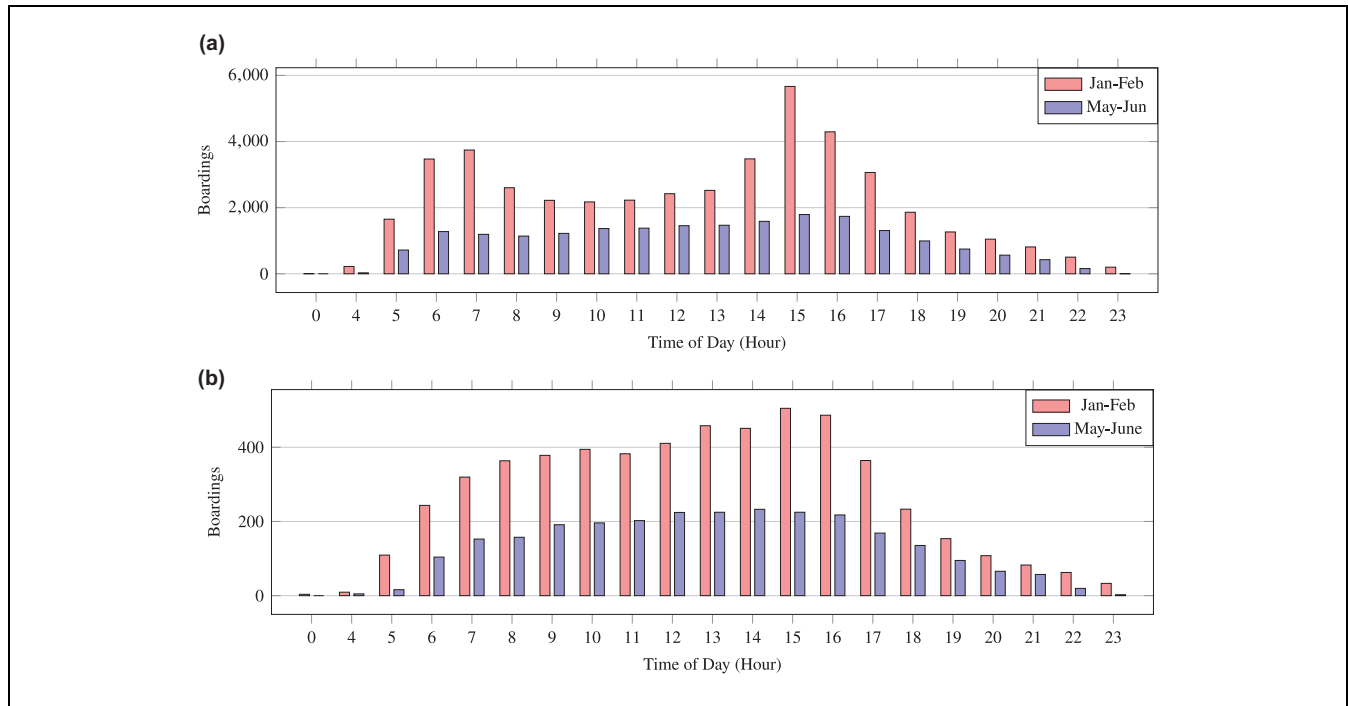


Figure 4. Average ridership by day for January to February and May to June 2020 for (a) Nashville and (b) Chattanooga. January to February represents the baseline pre-COVID ridership levels in 2020 whereas May to June represents ridership after it stabilized mid-COVID.

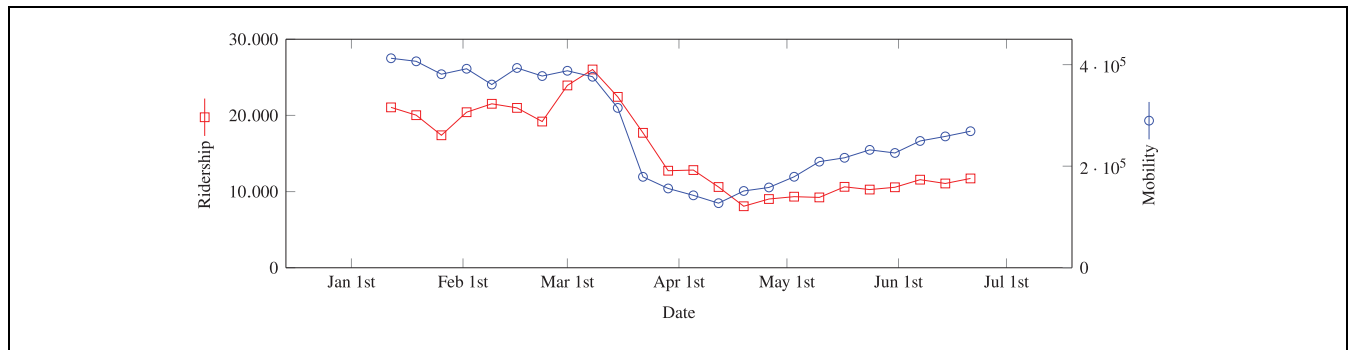
data (29) from January to July 2020 in Chattanooga. As shown, mobility in Chattanooga started to drop week

beginning March 15, 2020, the same week transit ridership started to decline steeply. The weekly low for





**Figure 5.** Average weekday boardings by time of day for January to February and May to June 2020 for (a) Nashville and (b) Chattanooga. January to February represents baseline pre-COVID ridership levels whereas May to June represents ridership after it stabilized mid-COVID.

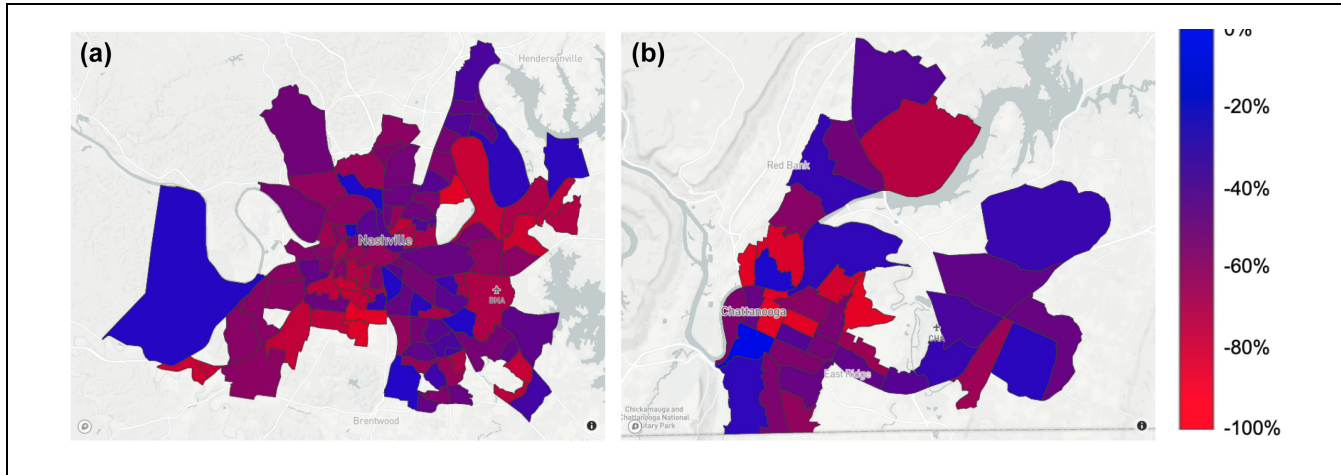


**Figure 6.** Chattanooga weekly ridership: weekly ridership compared with mobility (anonymized mobile location data) in Hamilton County, TN, from January through July 2020.

mobility was the week beginning April 12, 2020 in which there were 127,185 visits to POIs and 10,602 transit rides. The weekly low for transit ridership was 1 week later during the week of April 19, 2020 in which there were 8,735 transit rides and 151,210 visits to POIs. After their respective lows, mobility and transit ridership both recovered through May and June 2020. There were 268,868 visits to POIs and 11,725 transit rides during the week of June 21, 2020, which represented a 111% and 10% increase in mobility and transit ridership, respectively, between the weeks of April 12 (weekly low for

mobility) and June 21, 2020. Between the weeks of April 19 (weekly low for transit ridership) and June 21, 2020 there was a 78% and 45% increase in mobility and transit ridership, respectively.

Figure 7 shows the percent decrease in ridership between pre-COVID (January to February) and mid-COVID (May to June) operations per census tract. As shown, change in ridership was not uniformly distributed throughout either city. Both cities saw significant decreases downtown, most likely because of employees working remotely. This was most visible in Chattanooga



**Figure 7.** Change in ridership between pre-COVID (January to February) and mid-COVID (May to June) 2020 per census tract for (a) Nashville and (b) Chattanooga.

**Table 2.** Overview of Key Demographics for Nashville and Chattanooga, TN

	Total population	Median family income (USD)	Median housing value (USD)	Median gross rent (USD)	White (%)	African American (%)	Hispanic (%)
Nashville	650,806	65,317	206,464	967	63	27	10
Chattanooga	348,856	63,552	165,259	809	75	20	5

Note: USD = United States dollars.

where ridership decreased by up to 81%. Chattanooga also saw a significant decrease in ridership in the census tract that contains the University of Tennessee, reflecting the university’s decision to suspend in-person operations and CARTA’s subsequent cancellation of the free shuttle servicing this region. Although the same patterns were present in Nashville, change in ridership was more uniform, probably owing to the density of Nashville’s downtown region. Nashville saw significant decreases in ridership in areas heavily dependent on retail and shopping, including an 87% drop to Opry Mills and an 86% drop to Green Hills—the two largest shopping malls in Nashville.

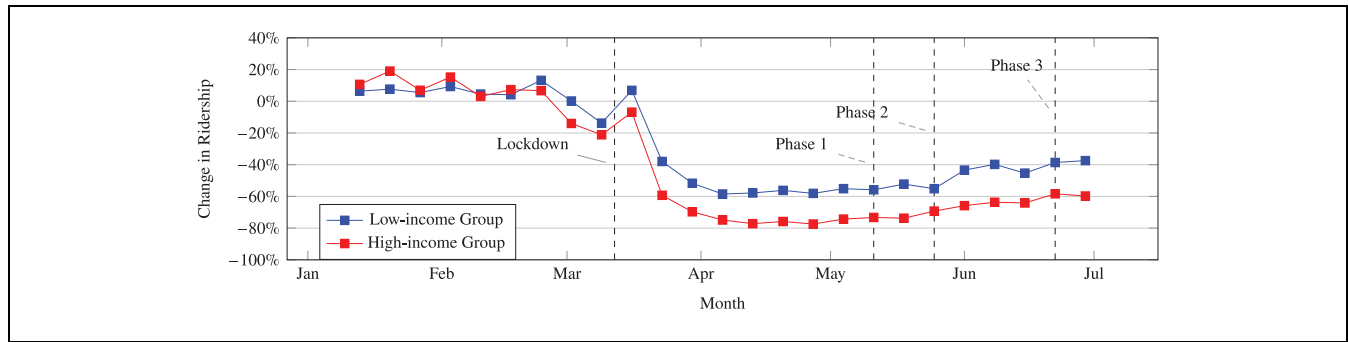
As we can see in this section, the biggest declines in ridership were on weekdays during the morning and evening commuting times. The comparison of transit ridership to mobility patterns in Chattanooga additionally indicated that foot traffic recovered to a greater degree than transit ridership. Therefore, there were likely to have been two competing factors at play. First, the declines in transit ridership on weekdays during the morning and evening commuting times indicated a possible persistent shift toward alternative work options throughout the COVID-19 pandemic. On the other hand, the greater recovery in mobility from the cellular dataset indicated a possible shift away from public

transit options. Lastly, the spatial variation in transit ridership showed that changes in ridership were not uniform throughout Nashville and Chattanooga.

### Socioeconomic Analysis and Explanatory Model

In this section we investigate the relationship between decreases in ridership and socioeconomic factors. An overview of the demographics for both cities is provided in Table 2 to give perspective on the makeup of the cities in this study. This investigation includes three components: changes in ridership between high- and low-income tracts (Figure 8), Pearson correlation values between a set of independent variables and relative ridership change (Table 3), and a linear regression analysis for identifying statistically significant associations (Table 4).

Figure 8 shows the change in weekly ridership for 2020 compared with the baseline ridership in 2019 for the 10% highest- and 10% lowest-income census tracts in Nashville. A greater decrease in ridership for the high-income compared with the low-income group (77% versus 58%) was found. The lows for both groups occurred during the week of April 27. The trend lines followed a similar trajectory for both groups, and no significant time shift was found. Furthermore, both groups saw



**Figure 8.** Change in ridership compared with 2019 baseline for the 10% highest- and 10% lowest-income census tracts in Nashville measured by median household income.

**Table 3.** Pearson Correlation Values for Relative Change in Ridership after COVID-19 in Nashville, TN (N = 94 Census Tracts)

Metric	Category	Pearson correlation
Median income	Residence	0.21
Median housing value	Residence	0.35
Median rent	Residence	0.15
Percentage White	Residence	0.01
Percentage African American	Residence	-0.02
Percentage Hispanic	Residence	-0.19
Percentage of jobs: White	Workplace	0.12
Percentage of jobs: African American, Hispanic	Workplace	-0.06
Percentage of jobs: no college degree**	Workplace	-0.43
Percentage of jobs: with college degree	Workplace	0.20
Percentage of jobs: entertainment, and food services	Workplace	0.17

Note: A positive correlation indicates that a larger independent variable leads to a larger relative impact, that is, a greater decrease in ridership. Residence variables refer to the demographics of those who live in the target census tract; workplace variables refer to the demographics of jobs located in the target census tract. \*p < 0.05; \*\*p < 0.01; \*\*\*p < 0.001.

**Table 4.** Socioeconomic Model for Relative Change in Ridership Between May 1 and July 1, 2020, Compared with the 2019 Baseline per Census Tract in Nashville (N = 94 Census Tracts)

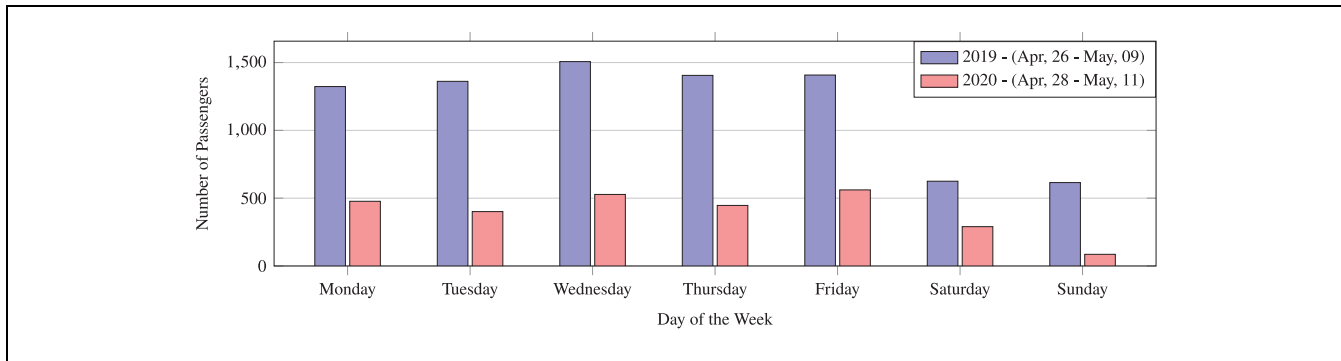
Variable	Category	Coefficient	SE	Z-value	P-value
Constant	na	0.556	0.015	36.971	0.000
Median housing value	Residence	0.019	0.020	0.908	0.366
Percentage Hispanic	Residence	-0.016	0.017	-0.928	0.356
Percentage of jobs: White	Workplace	0.007	0.018	0.372	0.711
Percentage of jobs: no college degree	Workplace	-0.052	0.019	-2.775	0.007

Note: SE = standard error; na = not applicable. A positive coefficient indicates that a larger independent variable leads to a larger relative impact, that is, a greater decrease in ridership. R<sup>2</sup>: 0.221; adjusted R<sup>2</sup>: 0.184; F-statistic: 5.901.

similar upward trends in ridership following their respective lows during the week beginning April 27, 2020.

As stated, the economic data from the U.S. Census Bureau (26) included a breakdown of racial demographics, income levels, and housing information for residents at the census tract level and we referred to this socioeconomic category as residence variables. From the LODS dataset (28) we extracted socioeconomic

information on workers employed in jobs within a census tract, which: workplace variables. There are 120 census tracts in Nashville. On average, some census tracts had very few boardings. To avoid outliers resulting from sparsely serviced census tracts, only tracts that had at least an average of 10 boardings per day between May 1 and July 1, 2020 were considered, resulting in a sample size of 94 census tracts. For the analysis presented in



**Figure 9.** Mean ridership by day of the week of paratransit services in Nashville between April 28 and May 11, 2020 compared with 2019 rates.

Tables 3 and 4 we investigated the relationship between the independent variables and change in ridership between May 1 to July 1 2020 compared with the same period in 2019 per census tract in Nashville. A positive Pearson correlation (Table 3) and a subsequent positive coefficient (Table 4) indicated that a larger independent variable led to a larger relative impact, that is, a greater decrease in ridership compared with the 2019 baseline.

In Table 3, the highest positive correlation with drop in ridership was for median housing value (0.35), that is, census tracts with high median housing costs had a greater reduction in ridership from the 2019 baseline. For workplace demographics, we saw a moderate negative correlation of  $-0.43$  between the percentage of jobs held by workers without a college degree and the drop in ridership. In this case, the more jobs in a census tract that were held by workers without a college degree, the less severe the drop in ridership.

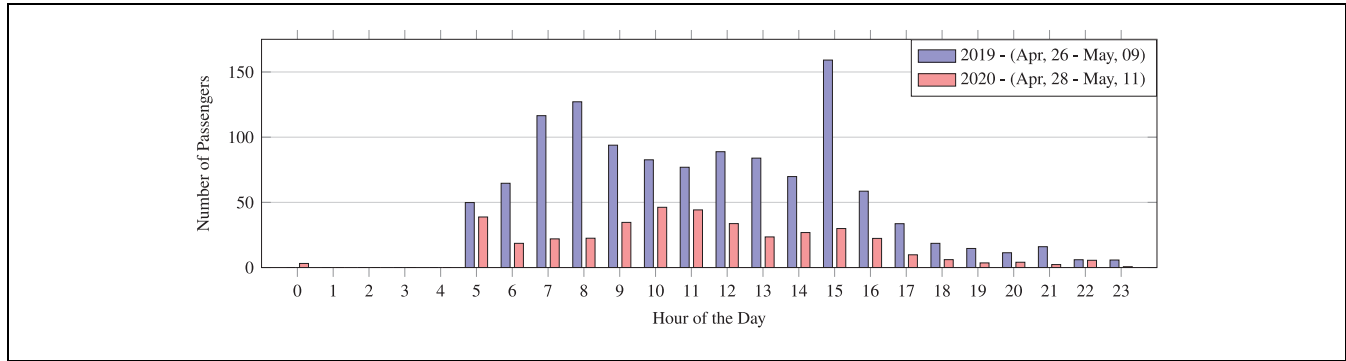
It is important to note that although the correlation values presented in Table 3 could provide high-level transit decision-makers insights into the relationship between socioeconomic variables and ridership change, they do not indicate a statistical association. Therefore, to clarify the relationship between the socioeconomic variables and ridership we designed a multiple linear regression model using ordinary least squares (OLS). There were two challenges in crafting a multiple linear regression model in this setting. The first was the potential for multicollinearity among the independent variables. In this setting, median income, median housing value, and median rent were highly correlated, therefore we removed median income and median rent, leaving median housing value since this variable had the highest Pearson correlation of the three. “Percentage of jobs: no college degree” and “percentage of jobs: with college degree” were highly related, therefore, we dropped the latter variable. The second related issue was the impact of confounding variables, that is, independent variables that are both associated with another independent variable and the dependent variable

(i.e., ridership change). Therefore, to craft a parsimonious model we adopted a two-step procedure. First, we ran a simple linear regression analysis between each of the remaining independent variables and identified four variables with  $p$ -values  $< 0.05$ , which we identified as potentially statistically significant: median housing value ( $p$ -value: 0.000), percentage Hispanic ( $p$ -value: 0.033), percentage of jobs: no college degree ( $p$ -value: 0.000), percentage of jobs: White ( $p$ -value: 0.037).

The four potentially significant independent variables were used in the multivariable OLS model presented in Table 4. All independent variables were  $Z$ -score-standardized so that the magnitude of the coefficients could be directly compared, and the dependant variable was represented as a fraction. The model had a relatively moderate  $R^2$  of 0.221 and adjusted  $R^2$  of 0.184. It is important to note that this model was not intended to be a comprehensive predictive model; its purpose was to identify statistically significant independent variables to guide transit agencies in their investigation of changes in ridership patterns resulting from the COVID-19 pandemic. With this in mind, we found that the percentage of jobs in a census tract held by workers without a college degree had the largest negative coefficient and was the only statistically significant variable ( $p$ -value  $< 0.01$ ). The large  $p$ -value change for the other three variables in the multiple linear regression model compared with their simple regression models indicated that median housing value, percentage Hispanic, and percentage of jobs: White were not significant when the variable percentage of jobs: no college degree was taken into account.

### Paratransit Usage and Rider Behavior in Nashville

Overall, there was a 66% decline in paratransit demand between April 28 and May 11, 2020 compared with the 2019 baseline in Nashville. As shown in Figure 9, there was an average decrease in paratransit demand of between 60% and 71% on weekdays, a decrease of 54% on Saturdays, and an 86% average decrease on Sundays.



**Figure 10.** Mean ridership based on the hour of the day of paratransit services in Nashville between April 28 and May 11, 2020 compared with 2019 rates.

The distribution of ridership demand compared with the 2019 baseline is provided in Figure 10. The largest decreases in demand were during morning peak, where there was an 81% decline from 7:00 to 9:00 a.m. and in the afternoon where there was also an 81% decrease in demand from 3:00 to 4:00 p.m.

Although there was a decline in ridership across all hours of the day, during COVID-19 paratransit demand was highest between 10:00 a.m. and noon, for which peak demand in the 2019 baseline was between 3:00 and 4:00 p.m., with significant demand during the morning peak from 7:00 to 9:00 a.m. This indicated a shift in rider behavior toward requesting rides in the middle of the day. Moreover, unlike fixed-line bus transit, paratransit service was not restricted during the duration of this study, therefore, decreased paratransit ridership was directly related to reduced demand. The temporal distribution of changes in ridership for paratransit in Nashville were similar to our findings for the changes in temporal distribution for fixed-line bus transit (Figures 4a and 5a).

### Transit Ridership Patterns Extended

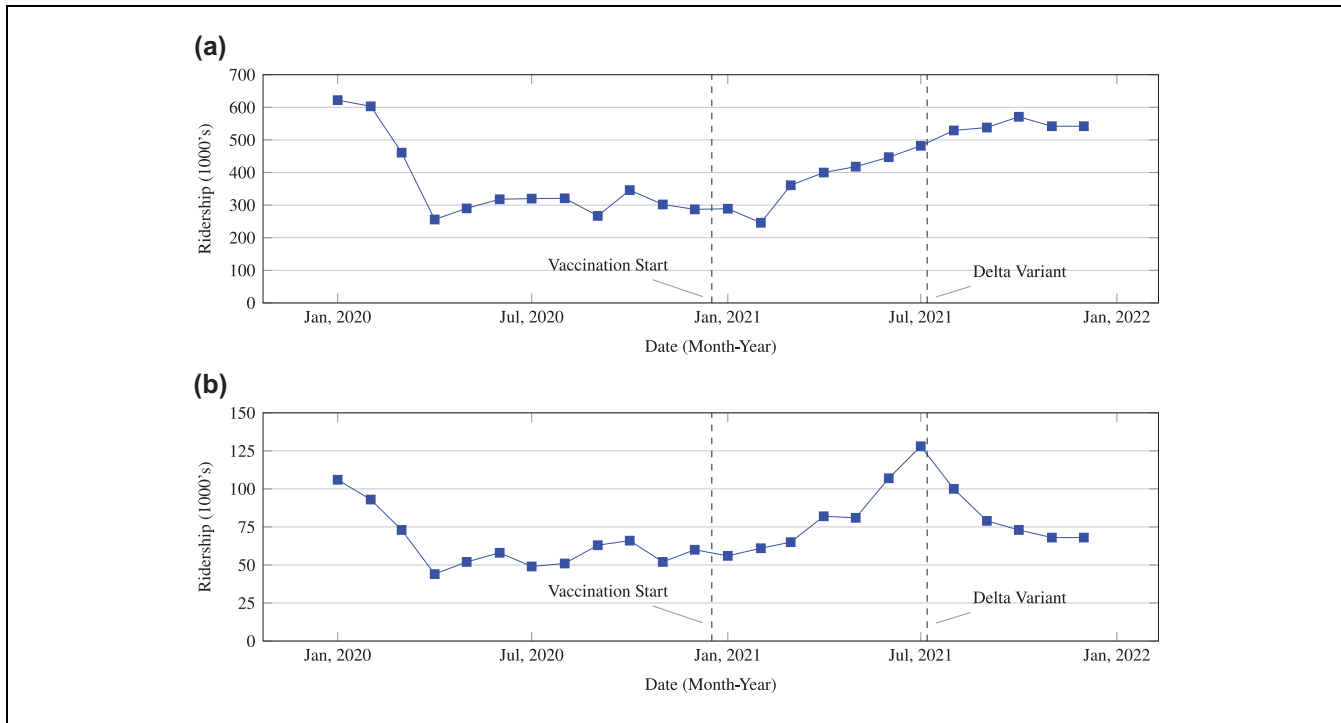
The ridership data available to us spanned January 1 to July 1, 2020. The extent of this work was therefore focused on the early stage of the COVID-19 pandemic. To provide a high-level overview of ridership trends since the initial submission of this work which spanned January 1, 2020 to July 1, 2020, we provide the monthly ridership for Nashville and Chattanooga from January 1, 2020 to January 1, 2022 in Figure 11. Ridership, as presented in Figure 11, was derived from automated passenger counter (APC) data available to us at monthly intervals. Through discussions with the transit agencies at Nashville and Chattanooga, it was surmised that the APC data were not as reliable the farebox ridership data used in the preceding sections of this work. This was largely because farebox data were derived directly from

payments or from the driver as passengers entered the bus, and the data were expected to be operational on all buses. However, owing to ongoing maintenance issues with APC devices, it was possible for buses to have been operating with inoperative or malfunctioning APC equipment. Therefore Figure 11 is included to provide additional context as to how trends evolved over the course of the COVID-19 pandemic through January 1, 2022.

Both cities appeared to see a second recovery starting in early January 2021, which was shortly after the first vaccinations were administered in Tennessee on December 17, 2020. As noted in Figure 11, the Centers for Disease Control recognized Delta as the dominant COVID-19 variant in the United States on July 7, 2021 (35). An interesting observation is that transit ridership in Chattanooga started to decline after July 7, 2021, however Nashville's transit ridership continued to recover to near prepandemic levels during the same period.

### Discussion and Recommendations for Transit Agencies

We now present the key takeaways from this work. First, Both cities saw similar patterns in ridership decline despite Nashville and Chattanooga having to cut vehicle trips by differing amounts. The initial decline in ridership occurred well before vehicle trips were reduced in either city. This indicated that other factors were influencing rider behavior outside of reductions in vehicle trips. Second, the largest declines in ridership were on weekdays during typical morning and evening commute times, indicating a potential persistent shift toward alternative work options or possibly a shift to greater use of personal vehicles. Mobility patterns in Chattanooga indicated that foot traffic recovered to a greater degree than transit ridership, adding weight to the idea that commuters in particular may have shifted mode to personal



**Figure 11.** Automated passenger counter monthly ridership for (a) Nashville and (b) Chattanooga between January 1, 2020 and January 1, 2022.

Note: The dashed lines indicate that December 17, 2020 was the date of the first vaccinations administered in Tennessee (34) and July 7, 2021 was the date in which the Centers for Disease Control recognized Delta as the dominant COVID-19 variant in the United States (35).

vehicles. Third, we observed that there was a wide spatial variance in ridership between census tracts that could be correlated with the socioeconomic characteristics of these areas. Our model showed that, on aggregate (per census tract), areas with a high concentration of jobs held by workers without a college degree maintained higher transit ridership. Fourth, we found that, despite the supply of paratransit not being restricted, the temporal distribution of changes in paratransit ridership in Nashville was similar to ridership patterns in fixed-line transit.

Cities should be aware that transit usage patterns changed as more high-income and college-educated workers were able to work remotely or switch to personal vehicles to travel to work. As restrictions from COVID-19 are relaxed, it will be important to continue monitoring these patterns to identify what is the new normal following the COVID-19 pandemic. In the context of this work, it is important that agencies prioritize transit access within areas comprising high concentrations of jobs for low-income workers and workers without a college degree. If high-income workers continue to work remotely, switch to hybrid schedules, or switch mode to personal vehicle, it will not only be more equitable to prioritize low-income regions of urban areas but could become more economical as these areas begin to comprise a greater overall share of a city's transit riders.

### Threats to Validity

Firstly, a limitation of this work is that it is focused on only two cities, both in Tennessee. Government restrictions vary greatly throughout the United States not only at the state- but city level. Even in this study, Nashville Metro—the local government of Nashville and Davidson County—systematically enforced restrictions that differed from the Tennessee state restrictions under which Chattanooga was regulated. Nashville followed a three-stage reopening plan, however, these stages many have comprised different restrictions compared with other cities and states. Moreover, although Nashville had recently moved to a more open Stage 3 in late June, it had reverted back to Stage 2 by July 3, 2020. However, we did not find that mixed messaging in relation to social distancing in late June had a major impact on ridership demand.

Secondly, public transit entails confining passengers to an enclosed space, whether social distancing is implemented or not. To date, there has been no known mass transmission of COVID-19 in Nashville or Chattanooga that originated on public transit. A well-publicized case such as this would most certainly have had a negative impact on ridership. Historically, mass transit has been a source of influenza and coronavirus transmission (7), however preliminary findings related to COVID-19 indicate that

fears of transmission via public transit may have been exaggerated (12). Regardless, it is imperative that transit agencies monitor safety and transmission in the setting of public transit.

## Conclusion

In this work we have presented a data-driven analysis of the impact of COVID-19 on ridership in Nashville and Chattanooga, TN. We investigated the impact of reductions in vehicle trips on ridership and performed a spatiotemporal analysis of changes in fixed-line bus usage. We additionally presented a socioeconomic analysis of transit ridership decline and offered recommendations for transit agencies as regulations related to COVID-19 are lifted. Lastly, we showed that paratransit operations were affected by COVID-19 in similar ways to fixed-line bus transit.

Future work will include developing low-cost image processing methods for ensuring social distancing on public transit. We also plan to use the analysis in this work to set the ground for agent-based simulation and modeling to predict ridership behavior as the COVID-19 pandemic continues to unfold, and to help transit agencies better adapt to future sudden systemic changes in ridership demand dynamics.

## Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: M. Wilbur, A. Ayman, P. Pugliese, D. Freudberg, A. Laszka, A. Dubey; data collection: V. Poon, A. Ouyang, R. Kabir, A. Vadali; analysis and interpretation of results: M. Wilbur, A. Ayman, A. Sivagnanam, A. Ouyang; draft manuscript preparation: M. Wilbur, A. Laszka, A. Dubey. All authors reviewed the results and approved the final version of the manuscript.





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