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RESEARCH REPORT

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Job Accessibility Impacts of Pandemic Transit Service Adjustments in the San Francisco Bay Area

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February 2025

Berkeley Institute of Transportation Studies

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16. Abstract

The COVID-19 pandemic forced transit agencies to quickly adapt to new challenges, with service reductions as part of the response to reduced ridership, rising fiscal pressures, and staffing shortages. However, approaches to service adjustment varied significantly across agencies. While pandemic research often focuses on ridership impacts, less attention has been given to how transit service changes affected accessibility and equity. This study examines the impacts of pandemic service adjustments made by three major San Francisco Bay Area transit agencies on accessibility and equity, which is important to address given the absence of formal requirements for equity evaluation of temporary service changes. Using publicly available transit schedule and census data, metrics for transit service levels, job accessibility, and accessibility inequality were developed and used to trace changes from 2020 to 2023. The findings reveal distinct approaches to service reduction and restoration, with agencies prioritizing service differently based on travel needs and racial/ethnic minority populations. While equity briefly improved for some agencies during the pandemic, these changes were temporary, with all agencies returning to their pre-pandemic states of inequity. These insights can guide transit agencies in developing equitable service adjustment strategies and highlight the need for decision-making tools to help transit operators balance competing needs and respond flexibly to disruptions.

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Executive Summary

Executive Summary

The COVID-19 pandemic significantly disrupted the transit industry, forcing agencies to balance safety and mobility in a time of uncertainty. Transit agencies quickly adapted to new challenges, adjusting services in response to reduced ridership, fiscal pressures, and staffing shortages due to illness. However, approaches to service adjustment varied significantly across agencies. Moreover, temporary service changes implemented during the pandemic did not require a service equity evaluation.[1] Given this and the potential for disproportionate burdens on vulnerable populations, this retrospective analysis is important to understanding these impacts and inform future transit disruption management strategies. While much of the pandemic research focuses on ridership, less attention has been given to how transit service changes affected employment access and social equity. Moreover, existing studies have primarily examined responses during the initial lockdown period, with few investigating the effects of transit service changes throughout and beyond the pandemic.

This study examined spatial and temporal patterns in service adjustments and evaluated the equity impacts on job accessibility for three major San Francisco Bay Area transit agencies between 2020 and 2023: the Alameda-Contra Costa Transit District (AC Transit), the San Francisco Bay Area Rapid Transit District (BART), and the San Francisco Municipal Transportation Agency (MUNI). Using publicly available census and transit scheduling data, metrics for transit service frequency, job accessibility, and accessibility inequality were calculated for four key phases between 2020 and 2023: Phase 1-existing (pre-March 2020), Phase 2-pandemic onset (April-June 2020), Phase 3-pandemic midpoint (September-October 2021), and Phase 4-current levels of service (December 2023). Transit service frequency was measured at the census block group level and compared across sociodemographic groups. Spatial distributions of percentage changes in service levels were plotted, and temporal patterns were analyzed by calculating the total number of unique trips in the system for each hour of the day. To assess the impacts of service changes, job accessibility via each transit system was calculated for a typical weekday during each phase and compared across sociodemographic groups. An interval-based cumulative opportunities measure was used to estimate the number of jobs accessible within 40-to-60-minutes travel time via transit between 7 am and 8 am. Inequalities in accessibility were quantified by income groups using the corrected concentration index (CCI).

The findings revealed three distinct approaches to service reduction and restoration. AC Transit's strategy of maintaining service in core urban areas and prioritizing transit-dependent populations suggests a deliberate effort to support those most reliant on public transportation. On the other hand, MUNI adjusted services in a way that prioritized neighborhoods with higher proportions of racial minorities. MUNI has also substantially increased service levels across the system to above existing pre-pandemic levels. BART reduced and restored service relatively evenly across the system, although it made slightly larger increases in areas with a higher

[1] Federal Transit Administration. Circular 4702.1B. Title VI Requirements and Guidelines for Federal Transit Administration Recipients. U.S. Department of Transportation, Oct 01, 2012, Chap. IV, Sec. 7.a(1)(a).

proportion of White residents. Both BART and MUNI have maintained pandemic-era changes that provided more uniform service levels throughout the day while AC Transit returned to concentrating services around the peak hour commute. MUNI saw the largest decrease in job accessibility, with overall access falling to 18 percent below pre-pandemic levels. While job access in most areas returned to existing levels by Phase 3 for BART and MUNI, that has not been the case for AC Transit. However, despite substantial service increases made by MUNI and BART to levels exceeding pre-pandemic levels, these increases did not generally translate into significantly higher levels of job access.

Sociodemographic analysis shows that service adjustments implemented by AC Transit and MUNI tended to minimize impacts to minority and low-income populations, while the impact of BART's changes were generally more evenly distributed across racial/ethnic and income groups. Finally, using the CCI as a measure of job inequality, the study found that while job access briefly improved for low-income travelers riding MUNI during the pandemic, these changes were temporary, with all agencies eventually returning to their pre-pandemic states as service cuts were restored.

Key insights from this study can inform the development of equitable transit service allocation for future disruptions. First, sociodemographic analysis of service changes showed that while each agency appeared to consider equity to some degree in their service adjustments, strategies and priorities varied between agencies. This highlights the need to evaluate the equity impacts of temporary service adjustments, in line with existing requirements for permanent service changes, to protect vulnerable populations during disruptions. Transit agencies should establish mechanisms for monitoring service changes and their equity impacts to respond dynamically to changing needs. Second, while accessibility equity metrics, such as the CCI, can provide insights into the potential impacts of service changes, they don't always consider factors such as service frequency and safety. Despite MUNI making substantial improvements in restoring service, these increases did not translate to significantly higher levels of job access, as measured by the accessibility metrics used in this study. Other metrics, including qualitative data, are needed to capture the full experience of riding transit during disruptions. Third, among the range of financial, constitutional, and operational constraints that transit agencies must balance, there are also multiple dimensions of equity to consider. For example, MUNI appeared to give higher priority to racial equity over travel needs by making smaller reductions in areas with higher proportions of minorities (see **Table 2**). Better decision-making frameworks and tools need to be developed to assist transit agencies in balancing competing needs effectively. Finally, the fact that some transit service actually became more equitable in terms of job access during the pandemic (see **Figure 7**) highlights an opportunity for transit agencies to build on those temporary improvements as they restructure their services for post-pandemic riders. By incorporating more robust response strategies for service allocation during disruptions, agencies can work towards long-term equity goals and improve overall resilience.

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Introduction

The COVID-19 pandemic seriously disrupted the U.S. public transit industry, forcing transit agencies to balance safety and mobility amid great uncertainty. Transit agencies took swift action on various fronts, including implementing public health and safety measures, attempting to protect their workforce from being laid off, and dealing with a widening budget gap brought about by escalating operating expenses and plummeting ridership revenue (*1–5*). Many agencies reduced services in response to decreased ridership, fiscal pressures, and staffing shortages.

Transit agencies adapted quickly to pandemic challenges, employing a range of strategies to protect employees and riders. Health and safety were a top priority for agencies. Many agencies increased vehicle and facility cleaning, instated requirements for mask-wearing, implemented back-door boarding, implemented social distancing measures, and suspended fare collection (*2*, *5–7*). Service adjustments were also a common strategy, although the extent varied significantly across agencies. At the onset of the pandemic, some agencies implemented major service reductions, while others applied a combination of reductions and additions or intentionally sought to maintain service levels for essential workers (*7*). Bus agencies tended to adopt weekend schedules or suspend routes, while rail agencies modified existing schedules by changing operating hours and service frequencies (*5*). Some bus operators suspended school and express routes and adopted weekend schedules, while others added additional service to hospitals (*2*).

However, the approaches to service adjustments and the extent to which equity considerations were integrated into decision-making varied significantly across agencies (*1*, *6*, *7*). In March 2020, 74 percent of surveyed transit agencies anticipated cutting service due to challenges imposed by the pandemic (*8*). By mid-2021, almost 90 percent of transit agencies in the U.S. had reduced service levels to some degree (*3*).

The degree and duration of service adjustments varied substantially over time. One study of multiple transit agencies found that with the exception of the Chicago Transit Authority, all agencies in the study initially reduced their service levels to between 40-80 percent of pre-pandemic levels, though, by early 2021 four out of the seven agencies were operating at near pre-pandemic levels, with the remaining agencies operating at 70-80 percent of pre-pandemic service (*1*).

Few agencies had a pre-existing pandemic response plan to guide how they adjusted their service. For example, one study found that only 15 percent of surveyed transit agencies had a plan (*5*), while another found that 35 percent of Texas agencies had a plan (*5*, *7*). Pre-existing plans were not always comprehensive, with some only covering aspects such as increased sanitization (*5*). Moreover, much of the guidance available "often focused single mindedly on mitigating viral transmission rather than maintaining access for essential riders" (*1*). In the absence of other guiding principles, many agencies used ridership data to identify changes in demand and inform service adjustments (*5*). Agencies had little guidance on how to adjust and prioritize service during the

pandemic, particularly for vulnerable populations, underscoring the importance of retrospective analysis to prepare for future disruptions.

The pandemic clearly underscored transit's role as a critical social service (*5*, *6*, *9–11*), providing access to essential destinations such as healthcare, grocery stores, and jobs. Studies of transit demand during the pandemic found that travel declined less among essential workers, lower-income populations, people of color, less educated populations, and those with limited mobility options (*2*, *9–14*). This suggests that these groups had less discretion over their travel choices as they continued to rely on transit throughout the pandemic, potentially exacerbating existing social vulnerabilities (*4*, *13*).

The Federal Transit Administration requires transit agencies to undertake a service equity analysis for permanent transit service changes to determine whether they may result in disparate impacts on minority populations or disproportionate effects on low-income populations (*15*, *16*). However, temporary service changes (lasting less than 12 months) implemented during the pandemic were exempt (*15*). Given that, this study undertook a retrospective analysis to understand what impacts these service adjustments may have had to inform future transit disruption management strategies.

This study traced service changes across four distinct phases of the pandemic, from disruption to recovery, over a three-year study period between 2020 and 2023 for the three major transit operators the San Francisco Bay Area: the Alameda-Contra Costa Transit District (AC Transit), the San Francisco Bay Area Rapid Transit District (BART), and the San Francisco Municipal Transportation Agency (MUNI). The findings reveal the three agencies had distinct approaches to service reduction and restoration, with uneven impacts across sociodemographic groups.

While much of the pandemic research has focused on impacts on ridership, limited attention has been given to transit supply and how changes to transit service may have impacted employment access among minority and low-income populations during the pandemic. This study analyzed the pandemic service adjustments made by the three agencies and evaluated changes in job accessibility between low income and higher income groups: Although some of the reductions in service resulted in relative (though not necessarily absolute) improvements in job access for low-income transit users compared to higher income groups, the disparities returned later, as service was restored by the end of the pandemic. Ultimately, this study provides valuable insights into how lessons learned from the pandemic could be used to develop equitable adjustment strategies for future service disruptions.

Study Area

Together, AC Transit, BART, and MUNI account for approximately 80 percent of the region's transit ridership, as measured by total unlinked passenger trips in 2022 (*17*). AC Transit primarily provides bus services, BART operates heavy rail, and MUNI offers a mix of bus, light rail, streetcar, and trolleybus services, with its bus

service representing the largest portion of ridership. The geographic coverage for each agency is shown in **Figure 1**.

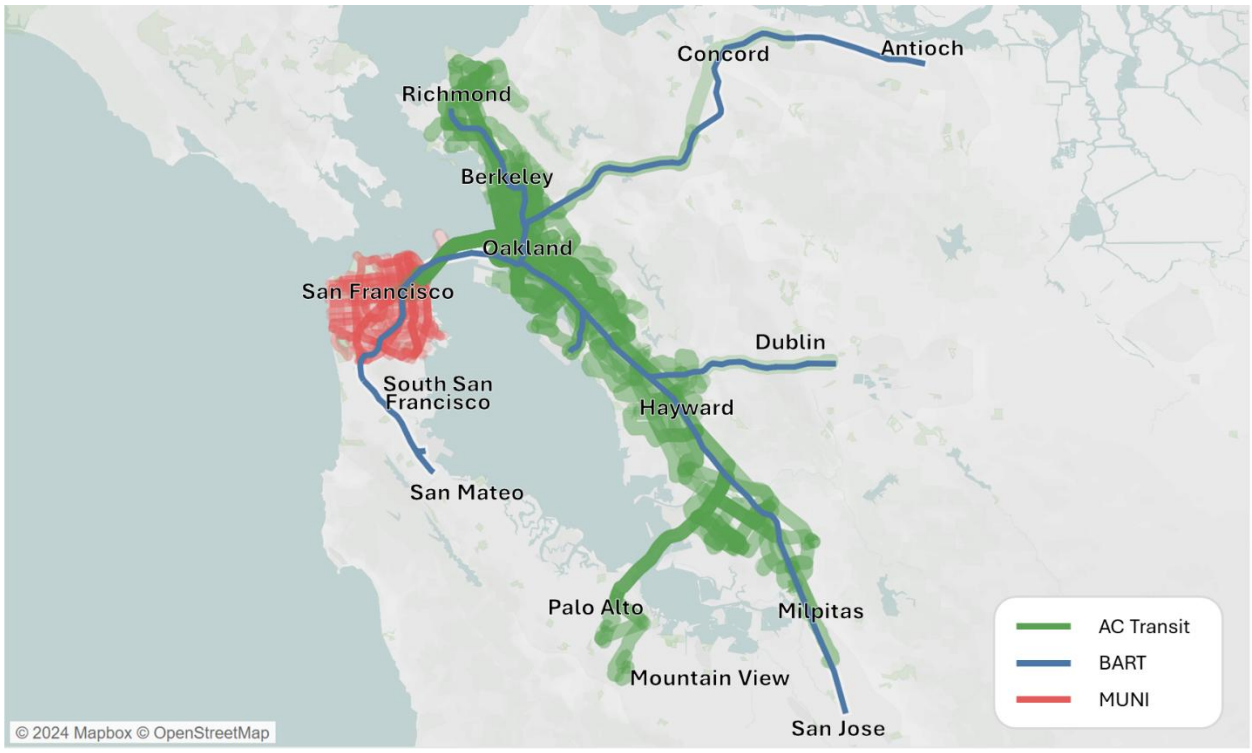

Figure 1. Routes operated by AC Transit, BART, and MUNI

Research Focus

Most studies have focused on the breadth of responses to the pandemic, whether that be examining the full spectrum of response strategies or covering a large geographical region. While this type of analysis is useful for quickly generating insights under rapidly evolving circumstances, specific details unique to each agency may be lost in aggregate analysis. There is a lack of detailed case studies that examine specific service adjustment patterns throughout the pre-pandemic, lockdown, and post-pandemic phases and the implications of these changes on both accessibility and equity. While some studies quantify aggregate transit service levels by measures such as service frequency (*1*, *6*), vehicle revenue hours (*18*), and the ratio of transit coverage to housing units (*19*), most do not report the magnitude of changes, instead focusing on high-level actions such as whether service was increased or decreased and often relying on self-reported survey responses from transit operators (*5*, *7*).

Some studies have begun to explore how transit agencies took into account the equity impacts of pandemic transit service adjustments (*1*, *4*, *6*). At the onset of the pandemic, some agencies appeared to focus on

horizontal equity (distributing benefits based on need) by limiting service reductions in more vulnerable communities while other agencies applied changes equally across income groups (*6*). On the other hand, while agencies varied in how they adjusted service, service changes had similar effects on all demographic groups throughout the pandemic (*1*).

A few studies have specifically examined the impacts of pandemic transit service changes on accessibility. One study of 22 cities quantified impacts on access to healthcare and grocery stores, finding that pandemic transit service cuts worsened access for many disadvantaged communities, especially in areas with high poverty levels, low-income workers, zero-vehicle households, and Black residents (*4*).

Many studies focus on the initial lockdown period of the pandemic. Our study focused specifically on quantifying the decree and distribution of service changes initiated by our three transit agencies during the whole pandemic period and the implications of these actions for job accessibility and social equity. Our specific research questions were:

- How did transit service levels vary geographically and throughout the day during the pandemic?
- How did service levels vary by sociodemographic groups?
- What impact did changes in service levels have on job accessibility, and how did this vary by sociodemographic groups?
- How did the overall equity of transit service allocation change throughout the pandemic?

The findings can help transit providers develop equitable service allocation strategies to better handle future pandemics or other disruptions. Appendix A presents an overview of relevant research on the COVID-19 pandemic response of North American transit agencies consulted for this study.

Research Approach

To answer the research questions, this study employed transit service frequency, accessibility, and equity metrics (**Figure 2**). Using publicly available census and transit schedule data, we quantified changes to transit service levels, then calculated changes in job accessibility via transit. To quantify the equity impacts of job accessibility impacts due to pandemic transit service changes, we utilize the corrected concentration index (CCI).

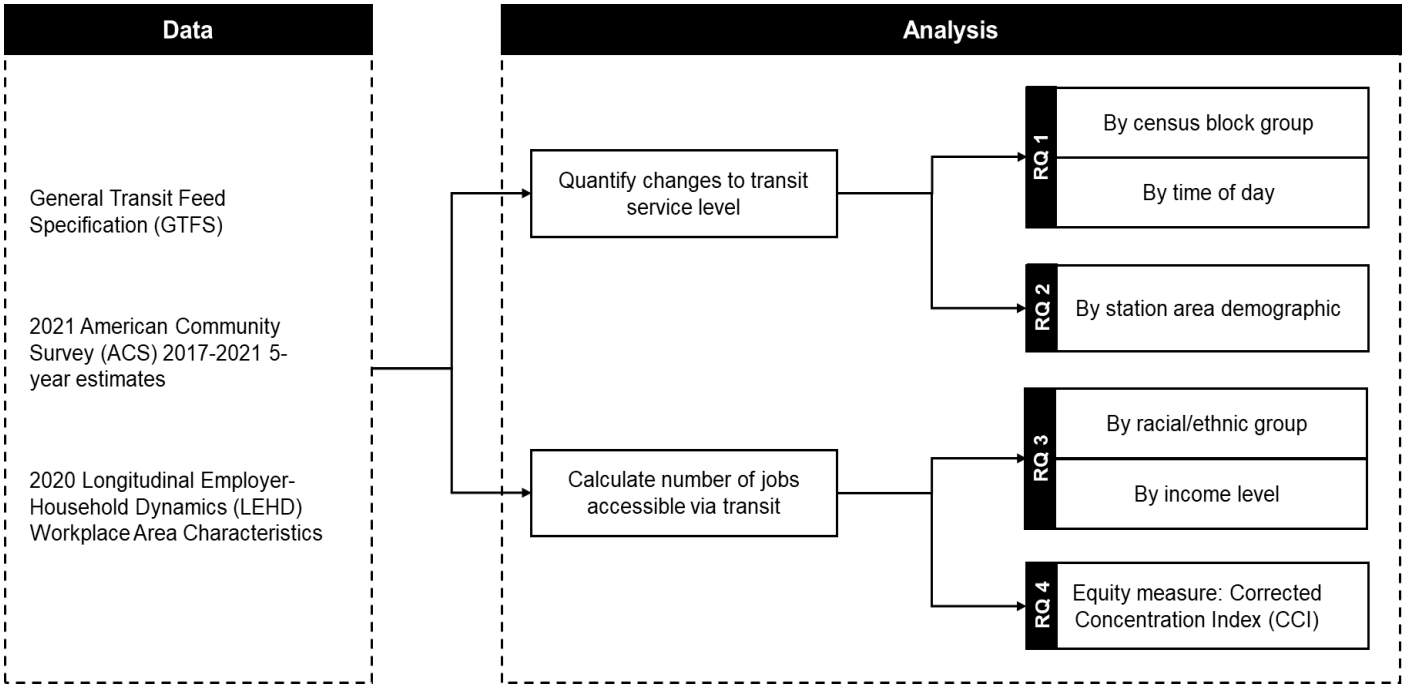

Figure 2. Overview of research process

Transit schedules from the General Transit Feed Specification (GTFS) (*20*) to quantify service changes implemented by agencies during four key phases of disruption, recovery, and restoration between 2020 and 2023:

- Phase 1: Pre-pandemic service levels (latest available feed prior to March 2020).
- Phase 2: Initial service reductions at the onset of the pandemic (selecting the feed with the lowest daily service hours between April and June 2020).
- Phase 3: Midpoint during the pandemic indicating intermediate service restoration (latest available feed from late September or early October 2021).
- Phase 4: Current service levels (latest available feed from December 2023).

One GTFS date was selected to represent each phase for each agency based on the criteria described above, though it was not always possible to select the same date across all three agencies due to data availability. **Figure 3** shows the four phases in relation to the number of weekly COVID-19 cases in California. The length of each phase denotes the range of GTFS dates used (e.g., for Phase 1, the latest available feed prior to March 2020 was August 9, 2019 for AC Transit, and February 18, 2020 for BART and MUNI).

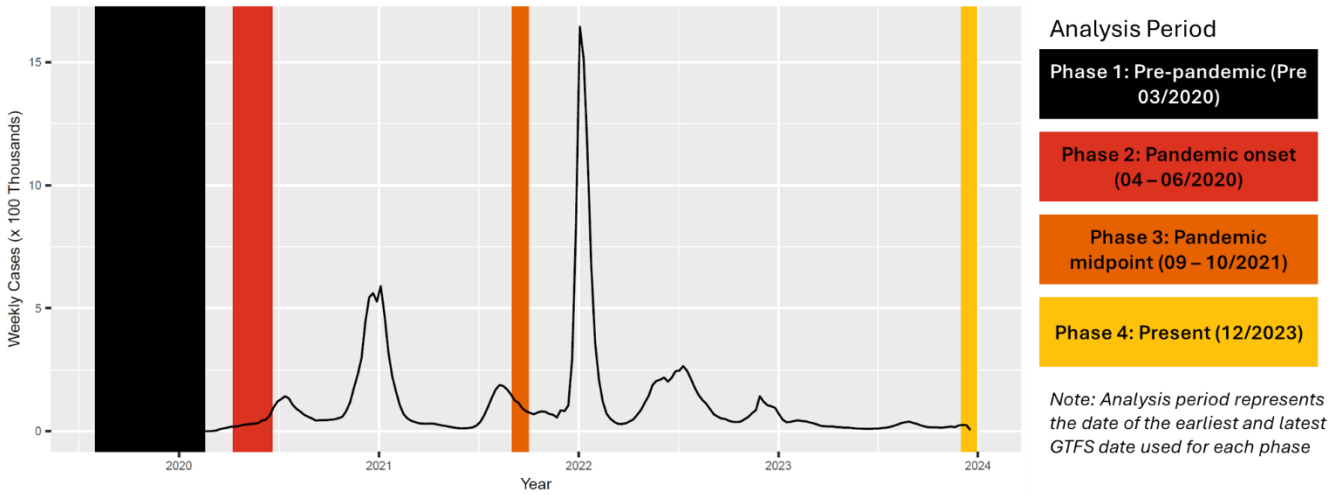

Figure 3. Weekly COVID-19 cases in California and key phases of study

Transit Service Adjustments

Quantifying Transit Service Changes

To measure service frequency, we calculated the total number of bus trips servicing all transit stops located within 0.25 miles of each block group on a typical Wednesday. This total was then divided by 24 hours to obtain the average hourly service frequency, which was used to calculate the percentage change in service levels between each phase.

We then compared the percentage change in service levels to sociodemographic characteristics for each block group using data from the 2021 American Community Survey (ACS) 2017-2021 5-year estimates. The magnitude of service reduction/restoration was divided into quartiles, rounded to the nearest 10 percent. We summarized the sociodemographic characteristics of each quartile of block groups, including commute mode, race, ethnicity, number of zero-vehicle households and low-income households. Low-income households were those with an income-to-poverty level ratio less than 200 percent of the Federal Poverty Level. Weighted two-sided t-tests were used to determine if the average changes for each quartile were statistically different from the overall average.

Figure 4 illustrates the geographic distribution of changes in average weekday service levels across the four phases of the pandemic for the three major transit agencies in this study. The first three plots for each agency depict changes in the magnitude of transit service for each block group relative to pre-pandemic levels, while the final plot shows the changes from the onset of the pandemic to current service levels, highlighting the extent of service restoration.

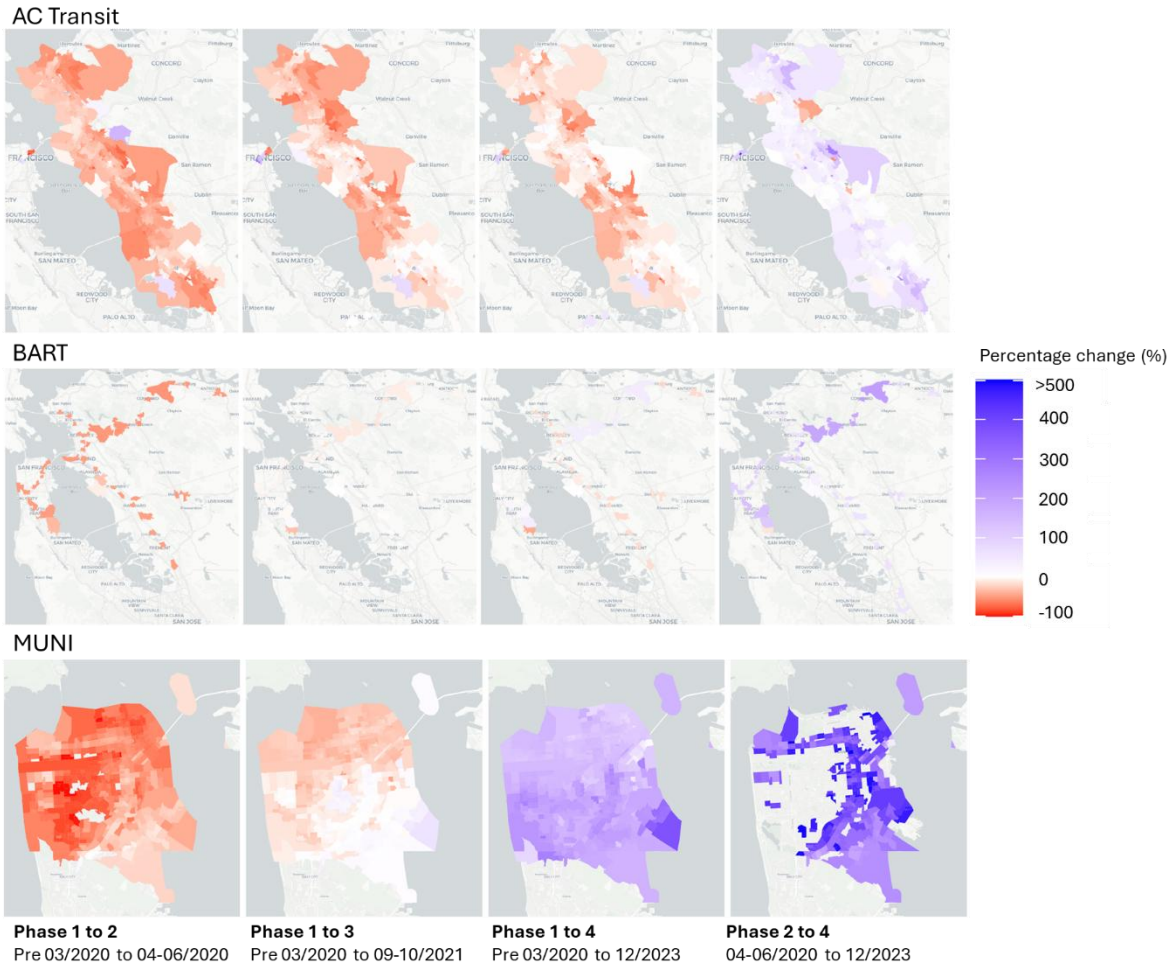

Figure 4. Changes in service levels by block group for AC Transit, BART, and MUNI between various stages of the pandemic

The data reveal three distinct approaches to initial service reductions and subsequent restorations. AC Transit prioritized maintaining service in core urban areas. While the agency reduced service levels across their service area, smaller reductions were made in areas such as downtown Oakland, which tend to serve local trips made by inner-city residents. Service levels have since gradually been restored to near pre-pandemic levels, though they generally remain slightly below existing levels.

BART initially reduced services uniformly across their system. However, the patterns of service restoration varied by geography. By late 2021, BART had restored services along the north-south corridor along the eastern region of the Bay to pre-pandemic levels. Subsequently, service levels along these lines were reduced again, with increases occurring on the east-west routes between the inland suburbs of the East Bay and South San Francisco through downtown San Francisco.

Although MUNI initially reduced service levels between Phase 1 and Phase 3, the reductions varied by area. Smaller reductions were made in the outer suburbs of the Peninsula in Richmond, Sunset, and Mission Districts, as well as neighborhoods south of Interstate 280. MUNI's post-pandemic approach to service restoration involved major increases in service levels across the board, particularly in areas such as the Sunset and Mission Districts, where it not only minimized service reductions but also implemented substantial service increases. On average, MUNI increased service 160 percent post-pandemic relative to pre-pandemic levels.

Figure 5 shows the evolution in system-wide hourly service levels over the course of the pandemic. Each agency exhibited distinct differences in the provision of peak-hour services. Initially, all three agencies reduced peak-hour services, making service levels more uniform throughout the day. Subsequently, each agency adopted different approaches to service restoration. AC Transit adopted a gradual approach, steadily increasing system-wide service levels at each subsequent phase. MUNI drastically increased service across the board, while BART initially restored services to pre-pandemic levels by September 2021 but subsequently scaled back these increases. While AC Transit reverted to more concentrated peak hour service, BART and MUNI opted to maintain pandemic-era changes in providing more uniform service throughout the day.

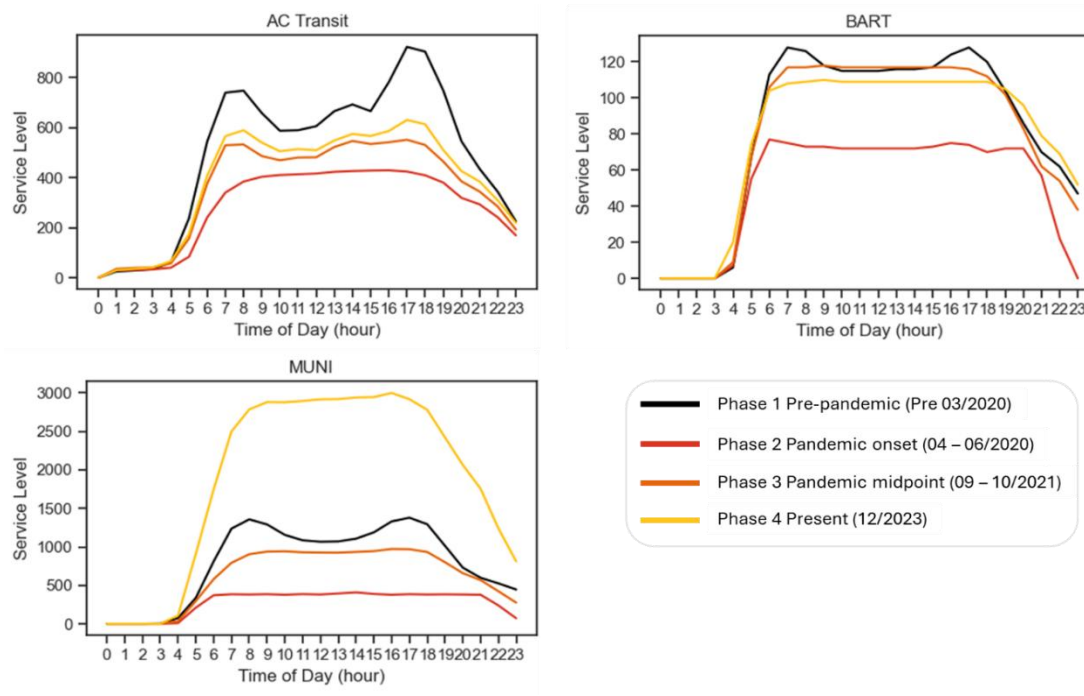

Figure 5. Hourly system-wide service levels for a typical weekday

Service Level Adjustments by Sociodemographic Characteristics

Table 1 shows the sociodemographic characteristics of block groups by percentage changes in service levels across Phase 1 and 2 when service was being reduced and Phase 1 and 4 after service was restored. Note that each sociodemographic group is measured at the population level with the exception of zero-vehicle households, which are measured at the household level.

AC Transit implemented more significant service reductions (over 40%) in areas with higher proportions of commute drivers and lower proportions of transit commuters, Black residents, zero-vehicle households, and low-income populations. For example, 71% of residents living in block groups that experienced over 40% reduction in AC Transit service between Phases 1 and 2 are commute drivers. Conversely, areas with a low proportion of commute drivers and a high proportion of zero-vehicle households experienced no changes or small increases in service, suggesting AC Transit prioritized service for transit-dependent populations.

BART reduced services uniformly, with each block group experiencing an average decrease of approximately 50 percent (standard deviation of 5%). As **Table 2** indicates this led to an opposite result from AC Transit: slightly larger reductions occurred in areas with a higher proportion of transit commuters and zero-vehicle households and a lower proportion of commute drivers. The reverse was also the case. These actions suggest that BART's service reductions potentially impacted transit users more significantly than drivers. No significant differences were observed related to race or income.

MUNI's adjustments appeared to prioritize racial minorities, although the overall changes present a mixed picture. Larger service reductions took place in areas with a higher proportion of White residents, while smaller reductions occurred in areas with a higher proportion of Hispanic residents. This pattern of smaller reductions in areas with a higher proportion of minorities also emerged for Black and Asian residents, though the differences were not statistically significant. Areas with fewer remote workers also experienced smaller reductions. However, smaller reductions also took place in areas with more automobile-owning households, and areas with higher proportions of automobile commuters. Assuming that areas with higher automobile access may not necessarily rely on transit services, the smaller reduction in these areas suggests there may have been a missed opportunity to redirect resources to areas with greater need for transit by implementing greater reductions in these areas. This mixed result underscores the challenges of balancing service allocation based on travel need (i.e. providing service in areas with limited automobile access and/or rely on transit to travel to work) and racial equity. The smaller reductions in minority-populated areas suggests that racial equity may have been a significant consideration in MUNI's service reduction strategy during the pandemic's onset, highlighting the complexity of balancing different priorities and achieving truly equitable service adjustments.

To assess sociodemographic differences in service restoration, we compared current service levels (Phase 4) to pre-pandemic levels (Phase 1). Although system-wide service levels generally remained below pre-pandemic levels, AC Transit restored service close to pre-pandemic levels in areas with higher proportions of zero-vehicle households and lower proportions of commute drivers. However, larger reductions persist in areas with more commute drivers, fewer transit commuters and zero-vehicle households, and in areas with higher proportions

of White residents and fewer Black and low-income residents, indicating a priority has been given to restoring service in transit-dependent areas. BART appears to have restored services relatively evenly across sociodemographic groups, though there is some evidence that restoration has been greater in areas with a higher proportion of White residents. MUNI implemented the most significant changes, increasing service levels beyond pre-pandemic levels. Nonetheless, these increases were unevenly distributed, with larger increases in areas with fewer White residents and more Hispanic residents, but also in areas with more commute drivers and those with fewer zero-vehicle households. If the agency had prioritized serving transit-reliant residents and zero-vehicle households, we would expect to see greater increases in service in these areas. However, this is not the case, suggesting that MUNI's service restoration strategy, like its reduction approach, may have considered racial equity as a determining factor over serving those with limited car access.

In summary, agencies implemented distinct approaches to service reduction and restoration. AC Transit maintained service for transit-dependent populations, restoring service to near pre-pandemic levels in areas with higher proportions of zero-vehicle households. BART adjusted service relatively evenly across population demographics, while MUNI appeared to prioritize service for racial minorities.

Table 1. Percent Change in Service Levels by Sociodemographic Characteristics

Phase	Agency	Percentage Change in Average Service Frequency	Proportion of Population								
			Commute drivers	Transit commuters	Working from home	White population	Black population	Hispanic population	Asian population	Zero-vehicle house-holds	Low-income population
Change in service from Phase 1 to Phase 2	AC Transit	<-40%	**0.71****	**0.10*****	0.15	0.34	**0.08****	0.24	0.35	**0.06*****	**0.17*****
		-40% to -30%	0.65	0.14	0.14	0.34	0.14	0.28	0.25	0.10	0.24
		-30% to -20%	0.59	0.16	0.15	0.31	0.14	0.30	0.26	0.15	**0.30****
		-20% to 0%	0.61	0.14	0.17	0.32	0.13	0.21	0.33	0.10	0.21
		>=0%	**0.34****	0.23	0.19	0.33	0.07	0.17	0.40	**0.48*****	0.21
	BART	<-50%	**0.40***	**0.28***	0.17	0.43	0.09	0.23	0.25	0.32	0.25
		-50% to 0%	**0.61****	**0.16****	0.14	0.31	0.11	0.28	0.33	**0.14****	0.23
	MUNI	<-70%	0.35	0.26	0.21	**0.52***	0.04	**0.10****	0.31	0.29	0.18
		-70% to -60%	0.31	0.28	0.18	0.44	0.05	0.13	0.35	0.39	0.22
		-60% to -40%	0.32	0.29	0.19	0.45	0.04	0.16	0.33	0.35	0.20
		-40% to 0%	**0.48****	0.28	**0.13***	**0.29*****	0.08	**0.23****	0.40	**0.20****	0.24
Change in service from Phase 1 to Phase 4	AC Transit	<-20%	**0.69***	**0.11***	0.15	**0.39***	**0.09***	0.25	0.29	**0.07*****	**0.17****
		-20% to -10%	0.65	0.13	0.16	0.34	0.12	0.27	0.28	0.10	0.22
		-10% to 0%	0.62	0.14	0.16	0.29	0.13	0.27	0.31	0.12	0.25
		>=0%	**0.54***	0.16	0.16	0.32	0.13	0.21	0.33	**0.23****	0.24
	BART	<-20%	0.52	0.18	0.16	0.41	0.13	0.23	0.25	0.20	0.27
		-20% to 0%	0.48	0.23	0.14	0.31	0.10	0.28	0.33	0.29	0.26
		>=0%	0.55	0.22	0.17	**0.48***	0.08	0.21	0.24	0.15	0.19
	MUNI	0% to 130%	**0.25*****	0.27	0.19	**0.51***	0.03	**0.10****	0.32	**0.43****	0.23
		130% to 150%	**0.29***	0.28	0.21	0.50	0.05	0.12	0.30	0.38	0.18
		150% to 190%	**0.45***	0.27R	0.16	0.38	0.05	0.16	0.39	**0.19*****	0.19
		>=190%	**0.46*****	0.29	0.15	**0.34***	0.06	**0.23***	0.37	**0.19****	0.21

*Note: *, **, or *** indicates that the sample proportion is significantly higher or lower than the overall proportion at the 0.1, 0.05, or 0.01 level.*

Job Accessibility Impacts

Job Accessibility Analysis

Job accessibility via each transit system was calculated for 7-8am for a typical weekday in each of the four phases. While there are limitations to focusing on individual transit agencies, this analysis provides initial estimates for impacts to accessibility specifically due to service changes. A typical weekday was identified as a Wednesday with no special events and the highest number of service runs. Employment data was obtained from the 2020 Longitudinal Employer Household Dynamics (LEHD) Origin-Destination Employment Statistics Workplace Area Characteristics data set, which provides the number of jobs per census block. Estimates were calculated for census block groups whose centroids fell within the service catchment area, which was defined as the 15-minute walking distance around each transit stop. Given that BART users access stations not only by walking, future work should estimate accessibility for other access modes such as driving, which is more typical of travel behavior in the San Francisco Bay Area.

Job accessibility was estimated by counting the average number of job opportunities that can be reached within 40 to 60 minutes from each census block, based on the average commute time via transit for the Bay Area in 2018 of 51.4 minutes (*21*). To address variation in departure times and service levels, travel times were calculated by generating a random departure time within each one-minute interval in the hour, taking the median travel time to calculate the final accessibility estimate (*22*, *23*). Details on how the accessibility index was calculated can be found in Appendix B.

Changes in access were compared for household income levels and racial/ethnic groups using ACS data. Four income categories were defined using quartiles of the median household income for census block groups in the service catchment area, with thresholds set at $8,667, $85,683, $118,083, $158,333, and $249,901.

Job accessibility closely mirrored adjustments to service as areas with reduced service also saw corresponding decreases in job accessibility. At the pandemic's onset, MUNI implemented the largest service reductions among the three agencies, resulting in an average 18 percent decrease in job accessibility (**Table 2**). However, substantial increases in service in the recovery phase did not lead to corresponding improvements in job accessibility. While MUNI service later increased beyond pre-pandemic levels, access generally did not exceed pre-pandemic levels, except in a few locations. As of December 2023, access for the service areas of BART and MUNI have been restored to pre-pandemic levels, while some areas of AC Transit's service area, namely San Mateo, Hayward, and Richmond, have yet to see job access fully restored.

The spatial distribution of job accessibility changes was largely driven by significant changes in specific regions (**Figure 6**). Job accessibility in downtown areas of East Bay cities was largely unaffected by service reductions made by AC Transit. However, minor changes to service in key job centers, such as downtown San Francisco, appear to have had a large impact. In each phase, service increases for specific routes led to major increases in

job access. For example, in Phase 2, increases to express routes serving East Bay commuters to downtown San Francisco drove significant increases in job access. While most of the region served by AC Transit has largely returned to pre-pandemic levels, some areas have lost access due to cancelled services. Notably, the M Line which connected two sides of the Bay across the San Mateo-Hayward Bridge was cancelled during the pandemic, with no plans to restore the service.

Overall impacts on job access via BART were generally minor. At the onset of the pandemic, inland suburbs of the East Bay, where service had been reduced more, experienced larger losses in accessibility. However, there were also large increases to job access with the opening of the BART Orange and Green Line extensions, with two new stations at Milpitas and Berryessa/North San José.

Initial changes to MUNI service led to decreases in job accessibility in the southwestern neighborhoods of San Francisco near the Sunset district and Ingleside. The agency also made some morning peak service increases at the onset of the pandemic to the neighborhoods around Bayshore Heights and Bayview, which were later reversed. Accessibility throughout most of the city was largely restored by the midpoint of the pandemic. Despite MUNI's substantial service increase beyond pre-pandemic levels, job accessibility did not improve to the same degree. We acknowledge that accessibility metrics do not capture MUNI's efforts to enhance service frequency and quality, which are major contributors to the ridership experience.

Table 2. Population-weighted Change in Job Accessibility by Station Area Sociodemographic Group

Sociodemographic Variable		Average change in job accessibility from Phase 1 to Phase 2			Average change in job accessibility from Phase 2 to Phase 4			Average change in job accessibility from Phase 1 to Phase 4		
		AC Transit	AC Transit	AC Transit	AC Transit	AC Transit	MUNI	AC Transit	BART	MUNI
Race / Ethnicity	White	4%	-8%	-8%	-8%	-4%	0%	4%	11%	24%
	Black	-1%	0%	0%	0%	-3%	6%	-1%	13%	12%
	Asian	6%	-5%	-5%	-5%	-3%	-1%	6%	9%	21%
	Hispanic	2%	-1%	-1%	-1%	-4%	0%	2%	9%	15%
Median Household Income Quartile	Low	-1%	-3%	-3%	-3%	-3%	3%	-1%	11%	7%
	Medium Low	5%	-7%	-7%	-7%	-3%	-3%	5%	13%	22%
	Medium High	5%	-11%	-11%	-11%	-6%	0%	5%	9%	26%
	High	14%	-2%	-2%	-2%	-5%	0%	14%	4%	28%
Overall Population		-8%	3%	-5%	-5%	-5%	0%	3%	10%	21%

Pandemic service changes impacted job accessibility to varying degrees across sociodemographic groups. While accessibility was reduced to a similar degree (11-13%) across racial/ethnic groups for BART, reductions were slightly smaller relative to reductions for the overall population for Black and Hispanic populations in the service areas of AC Transit and MUNI. Similarly, low-income populations were impacted least by AC Transit and MUNI service reductions, while high-income groups were least impacted by BART service reductions. These accessibility estimates offer additional insights into how service changes might have impacted groups unevenly, with reductions made by AC Transit and MUNI minimizing impacts to minority and low-income populations.

In line with AC Transit's service restoration program, job accessibility for Black, Hispanic, and low-income populations was generally maintained at pre-pandemic levels. Other groups who experienced larger initial reductions also received larger increases in access as services were restored. MUNI's service increases showed similar trends, with average accessibility returning to pre-pandemic levels. However, despite MUNI increasing service levels substantially beyond pre-pandemic levels, corresponding increases in job accessibility were not observed, except for Black and low-income populations, whose access increased by six percent and three percent, respectively. Subsequent increases in BART service were slightly larger for Black, White, and lower-income groups, leading to job accessibility for all groups being restored to within three to six percent of pre-pandemic levels.

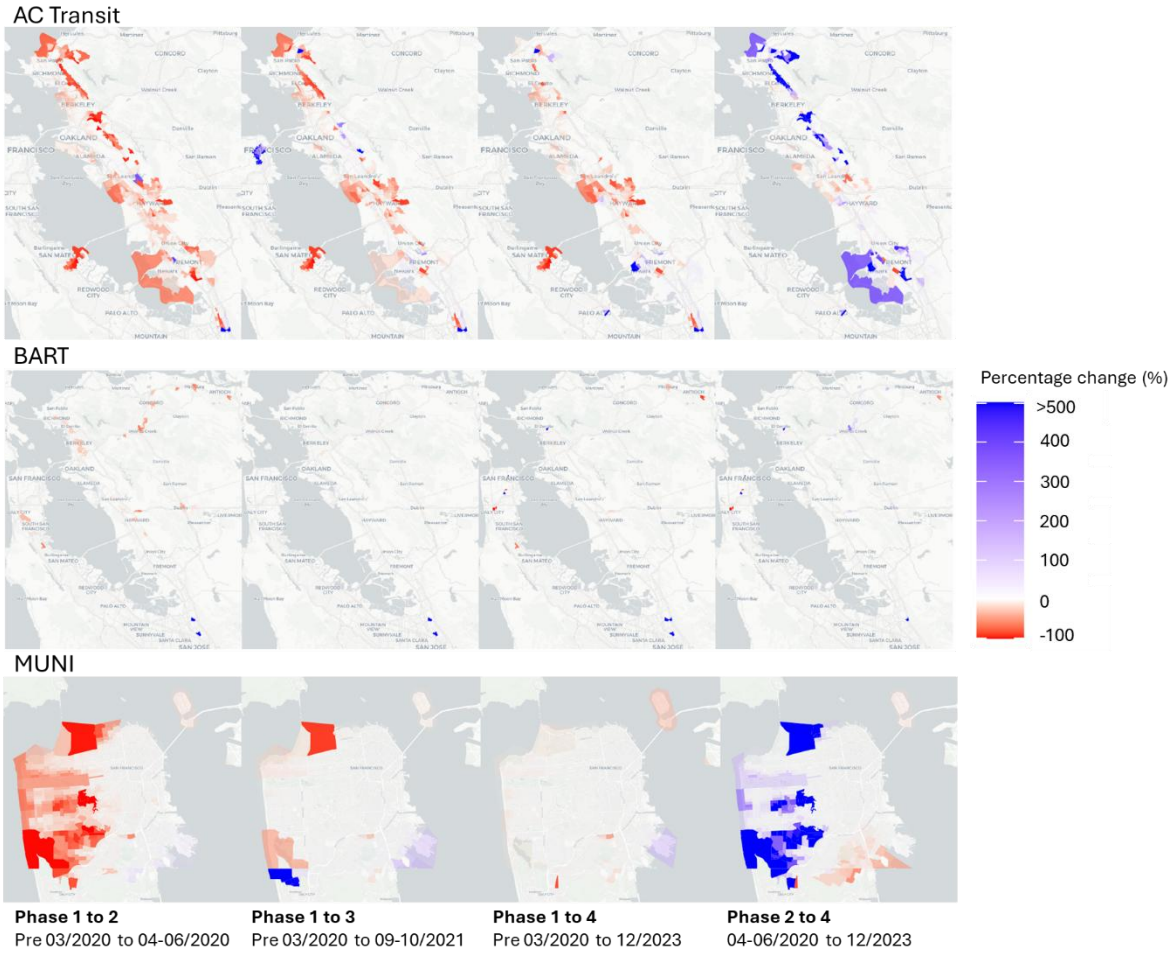

Figure 6. Percentage change in job accessibility via transit across different phases of the pandemic

Service Equity Evaluation

The job accessibility estimates in each phase were used to calculate the an index of differences in job accessibility as a measure of equity. We used the corrected concentration index (CCI) to estimate the degree of inequality in job accessibility between different block groups based on their socioeconomic status (*24*). Values range between -1 and 1, with negative values indicating that lower-income block groups have higher job access than higher income block groups while positive values indicate inequalities that favor higher-income block groups. Zero represents equality of job access with respect to socioeconomic factors, meaning that neither low-income nor higher income areas had greater job access. Values close to zero indicate more equitable conditions, while values closer to -1 or 1 suggest less equitable conditions. The main advantage of the CCI is that it captures both the direction and magnitude of the relationship between job accessibility. The formula for calculating the CCI can be found in Appendix B.

Prior to the pandemic, differences in job accessibility via MUNI favored higher-income block groups, while BART and AC Transit had relatively higher job accessibility for lower-income block groups. This relative advantage for lower-income block groups on BART and AC Transit persisted throughout the pandemic (**Figure 7**). Both agencies experienced minor fluctuations in the degree of inequality. MUNI experienced the largest changes in inequalities. This could have been part of a conscious effort by the agency to reallocate service to areas with greater need, such as those with more essential workers. The large reductions in service favoring high-income riders at the onset of the pandemic surprisingly improved equity, with the magnitude moving to slightly below 0. However, these improvements were temporary, with the CCI reverting to positive by the midpoint of the pandemic, and close to its original magnitude by the end.

Based on the CCI metric, all agencies have returned to their pre-pandemic levels of equity or inequity in terms of morning peak job accessibility. This phenomenon was also observed in a study of the Inland Empire in Southern California, where the return of bus routes to their pre-pandemic configurations also led to the return to existing inequalities (*19*).

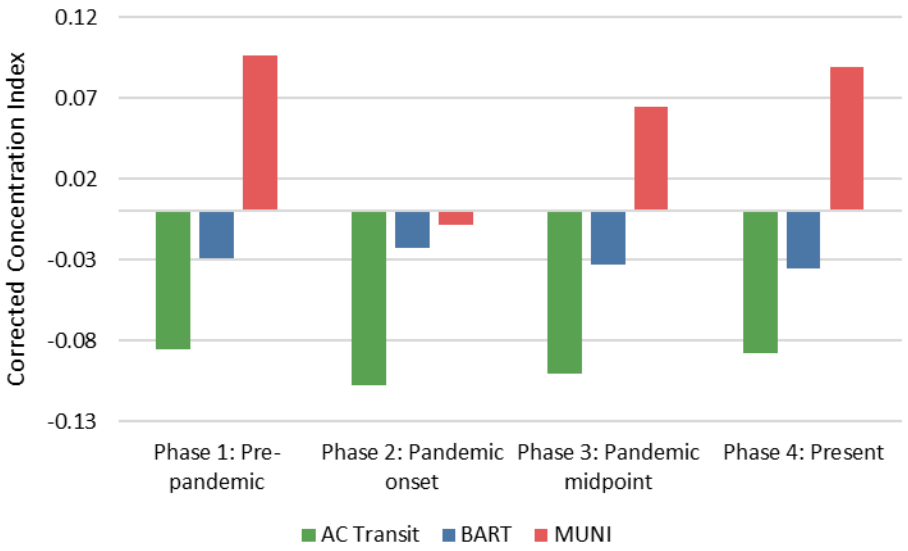

Figure 7. Changes in job accessibility inequalities

Conclusion

Lessons learned from the pandemic era are essential for improving preparedness for future disruptions. This study examined service adjustment patterns and evaluated the equity impacts on job accessibility for three major Bay Area transit agencies. The findings revealed three distinct approaches to service reduction and restoration. AC Transit's strategy of maintaining service in core urban areas and prioritizing transit-dependent populations suggests a deliberate effort to support those most reliant on public transportation. On the other hand, MUNI adjusted services in a way that prioritized neighborhoods with higher proportions of racial minorities rather than those with greater travel needs (i.e. areas with a higher proportion of zero-vehicle households and transit commuters). MUNI has also substantially increased service levels across the system beyond pre-pandemic levels. BART reduced and restored service relatively evenly across the system, although slightly larger increases were made in areas with a higher proportion of White residents. In terms of daily service patterns, both BART and MUNI have maintained pandemic-era changes of providing more uniform service levels throughout the day while AC Transit returned to concentrating services around the peak hour commute.

Pandemic service adjustments impacted job accessibility to varying degrees across agencies and across sociodemographic groups. MUNI saw the largest decrease, with overall access falling to 18 percent below pre-pandemic levels. While access in most areas was restored to existing levels by Phase 3 for BART and MUNI, for AC Transit job access has yet to return to pre-pandemic levels in San Mateo, Hayward, and Richmond. Despite substantial service increases made by MUNI and BART, these increases did not generally translate into significantly higher levels of job access, likely because job accessibility is also constrained by the geographic distribution of employment centers. Increased service can only improve job access to a certain extent, as job opportunities within a 40- to 60-minute transit window may be limited.

Sociodemographic analysis of accessibility impacts offers additional insights into how service might have impacted groups unevenly. Results show that impacts generally aligned with each agencies' patterns of service adjustment. Changes implemented by AC Transit and MUNI tended to minimize impacts to minority and low-income populations, while BART's impacts were generally more evenly distributed across racial/ethnic and income groups. Finally, using the CCI as a measure of job accessibility inequality, the study found that while equity briefly improved for MUNI and AC Transit during the pandemic, these changes were temporary, with all agencies returning to their pre-pandemic states.

Key insights from this study can inform the development of equitable transit service allocation for future disruptions. First, sociodemographic analysis of service changes showed that while each agency appeared to consider equity to some degree in their service adjustments, strategies and priorities varied between agencies. This highlights the need to evaluate the equity impacts of temporary service adjustments, in line with existing requirements for permanent service changes, to protect vulnerable populations during disruptions. Second, while accessibility and equity metrics, such as the CCI, can reveal insights into the potential impacts of service

changes, they are limited in their ability to consider factors such as service frequency and safety. Results show that despite MUNI's substantial service increases in the restoration phase, these increases did not necessarily improve job access. Additional information, including qualitative data, could be useful, in explaining how transit service relates to employment access and other types of accessibility. Third, among the range of financial, constitutional, and operational constraints that transit agencies must balance, there are also multiple dimensions of equity to consider. For example, MUNI appeared to give higher priority to racial equity over serving areas possibly greater need for transit services (**Table 2**). Transit agencies would benefit from clear protocols for identifying equity concerns in addressing riders' travel needs in inaugurating both temporary and permanent service changes. Last, the fact that preexisting inequalities in job access returned when service was restored (**Figure 7**) highlights a missed opportunity for transit agencies to build on temporary equity improvements. By incorporating equity measures into service allocation decisions during future disruptions, agencies can work towards long-term equity goals and improve overall resilience.

There are limitations to this study. First, several elements of the analysis could be refined to provide a more complete picture of the impacts of service changes. For example, the accessibility analysis focused only on job opportunities within the morning peak hour. Future work should include other destinations and time periods. Job accessibility was calculated for each agency separately to isolate each agencies' service changes. Multi-modal accessibility analysis would provide more realistic estimates although different methods would be required to isolate service changes. Additionally, qualitative investigation into how transit agencies incorporated equity considerations would provide necessary context for understanding service adjustment approaches. This study analyzed only three Bay Area transit agencies; future studies should extend the sample to include other agencies to compare performance and identify best practices.

In summary, this study offers new insights into how transit agencies responded to the COVID-19 pandemic regarding service adjustments and their effect on job accessibility and social equity. The findings may guide transit agencies in developing equitable service adjustment strategies, highlighting the need for decision-making tools to balance competing needs and respond flexibly to service disruptions.

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Appendix A. Studies Consulted

Table 3. Overview of Existing Studies on North American Transit Agencies' Pandemic Response

Author(s)	Study Area	Analysis Period	Transit Agency Response Examined				Impacts Assessed	
			Health and Safety	Labor and Staffing	Customer Communication	Service Changes	Accessibility	Equity
DeWeese et al. (2020) (*6*)	30 US and 10 Canadian cities	February and April / May 2020				✓		✓
Diaz et al. (2021) (*25*)	25 Canadian cities	March to June 2020	✓		✓	✓		
Kar et al. (2022) (*4*)	22 US cities	January to December 2020					✓	✓
Dasmalchi and Taylor (2022) (*18*)	3 US bus transit agencies	April to October 2020				✓		✓
Kurzhanskiy and Lapardhaja (2022) (*2*)	3 bus transit agencies in the Bay Area	March 2020 to March 2021	✓			✓		
Zhang et al. (2022) (*26*)	40 US transit agencies	January 2020 to August 2021			✓			
Karner et al. (2023) (*1*)	7 major US transit agencies	February 2020 to February 2021			✓	✓		✓
Mahmoudzad et al. (2023) (*7*)	Transit agencies in Texas	March 2020	✓	✓	✓	✓		
Speroni et al. (2023) (*5*)	72 US transit agencies	September and October 2020	✓	✓	✓	✓		
Collins et al. (2023) (*19*)	3 transit agencies in Southern California	September 2019 to December 2021				✓		✓

Appendix B. Methodology

Travel Time

Travel time matrices were generated using the statistical package "R" library *r5r* and job accessibility estimates were generated using the companion R library *accessibility* (*27*, *28*). Origin and destination centroids were weighted by population and number of workers respectively. Based on a previous study showing that most pedestrians are willing to walk up to ½ mile to access stations (*29*) and using the *r5r* default walking speed of 3.6 kilometers per hour, a maximum walking time of 15 minutes was assumed for this analysis.

Cumulative Job Accessibility Measure

Equations 1 and **2** were used to calculate the interval-based cumulative job accessibility measure at the block group level. Accessibility for different sociodemographic groups was calculated by weighting estimates by the number of people/households and the proportion of area covered by the service catchment area, based on methods used in the accessibility and equity literature (*30*, *31*).

$$A_{i,T} = \sum_{j=1}^{n} O_j \cdot f(t_{ij}) \qquad (1)$$

Where is the cumulative accessibility at origin within the travel time threshold , is the number of jobs at destination , is the travel time in minutes between the origin and destination, and is the travel time impedance function, which is an indicator function that takes values of 0 or 1 depending on whether the travel time is above or below the travel time threshold.

$$A_{i,I} = mean\left(\{A_{i,T} \; \forall \; T \; \in I\}\right), I = \; [T_{min}, T_{max}] \qquad (2)$$

Where is the average cumulative accessibility at origin within the travel time interval , and is a minute-by-minute distribution of travel time cutoffs within a given time interval between and .

Corrected Concentration Index (CCI)

The CCI was calculated using **Equations 3** and **4**:

$$w_i = r_i - \left(\frac{n+1}{2}\right) \qquad (3)$$

$$CI = \frac{8}{n^2(m_x - n_x)} \sum_{i=1}^{n} a_i w_i \qquad (4)$$

Where is the socioeconomic rank of block group , is the total number of block groups, is the weight for block group , is the maximum value of accessibility, is the minimum value of accessibility, and is the accessibility for block group . In this analysis, median household income was used for the socioeconomic rank.