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Public transit ridership in California declined in the five years before the pandemic of 2020–21 and dropped significantly further after the pandemic began. A sharp downward step in the level of transit boarding occurred after February 2020, and continues to the date of this report as a result of the public-health guidance on social distancing, expanded work-at-home, and a travel mode shift from public transit to private cars. A critical issue has come to the foreground of public transportation policy, namely, how to increase the quality and geographic reach of transit service to better serve the essential trips of mobility disadvantaged citizens who do not have access to private vehicle travel. The research focus of this report is an examination of the circumstances where fixed route bus route service could cost-effectively be replaced by on-demand microtransit, with equivalent overall zone-level efficiency and a higher quality of complete trip service. Research methods were reviews of documented agency experience, execution of simple simulations, and sketch-level analysis of 2019 performance reported in the National Transit Database. Available evidence is encouraging and suggestive, but not conclusive. The research found that substitutions of flexible microtransit for fixed route buses are already being piloted across the U.S., with promising performance results. The findings imply that action steps could be taken in California to expand and refine an emphasis on general purpose microtransit in corridors and zones with a relatively high fraction of potential travelers who are mobility disadvantaged, and where traditional bus routes are capturing fewer than 15 boardings per vehicle hour. To be sufficiently productive as fixed route replacements, microtransit service technologies in the same or larger zones need to be capable of achieving vehicle boardings of five per hour, a challenge worth addressing with technology applications.

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Steps to Supplement Park-and-Ride Public Transit Access with Ride-and-Ride Shuttles

John S. Niles, MS
J.M. Pogodzinski, PhD

Photos courtesy of Via Transportation, Inc.

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Founded in 1991, the Mineta Transportation Institute (MTI), an organized research and training unit in partnership with the Lucas College and Graduate School of Business at San José State University (SJSU), increases mobility for all by improving the safety, efficiency, accessibility, and convenience of our nation's transportation system. Through research, education, workforce development, and technology transfer, we help create a connected world. MTI leads the Mineta Consortium for Transportation Mobility (MCTM) funded by the U.S. Department of Transportation and the California State University Transportation Consortium (CSUTC) funded by the State of California through Senate Bill 1. MTI focuses on three primary responsibilities:

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Steps to Supplement Park-and-Ride Public Transit Access with Ride-and-Ride Shuttles

John S. Niles, MS
J.M. Pogodzinski, PhD

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Public transit ridership in California declined in the five years before the pandemic of 2020–21 and dropped significantly further after the pandemic began. A sharp downward step in the level of transit boarding occurred after February 2020, and continues to the date of this report as a result of the public-health guidance on social distancing, expanded work-at-home, and a travel mode shift from public transit to private cars. A critical issue has come to the foreground of public transportation policy, namely, how to increase the quality and geographic reach of transit service to better serve the essential trips of mobility disadvantaged citizens who do not have access to private vehicle travel. The research focus of this report is an examination of the circumstances where fixed route bus route service could cost-effectively be replaced by on-demand microtransit, with equivalent overall zone-level efficiency and a higher quality of complete trip service. Research methods were reviews of documented agency experience, execution of simple simulations, and sketch-level analysis of 2019 performance reported in the National Transit Database. Available evidence is encouraging and suggestive, but not conclusive. The research found that substitutions of flexible microtransit for fixed route buses are already being piloted across the U.S., with promising performance results. The findings imply that action steps could be taken in California to expand and refine an emphasis on general purpose microtransit in corridors and zones with a relatively high fraction of potential travelers who are mobility disadvantaged, and where traditional bus routes are capturing fewer than 15 boardings per vehicle hour. To be sufficiently productive as fixed route replacements, microtransit service technologies in the same or larger zones need to be capable of achieving vehicle boardings of five per hour, a challenge worth addressing with technology applications. Delivery of microtransit service can be undertaken through contracts with a growing set of private sector firms, which are developing processes to merge general purpose customers with those now assigned to ADA-required paratransit and Medi-Cal-supported non-emergency medical transport.

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All the analysis, conclusions, and recommendations in this report are the independent judgments and sole responsibility of the two named report authors, with no organizational endorsements received or meant to be implied.

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Executive Summary

The original intent of this research was to outline options for public ride services feeding to high-capacity fixed route transit as a replacement for park-and-ride facilities at rail transit stations and bus transit centers, using Santa Clara Valley Transportation Authority (VTA) as a case study.

However, the pandemic erupted as the project was beginning in early 2020; rail and bus ridership dropped, park-and-ride lots became nearly empty, and the researchers perceived that the original focus of shuttles to park-and-ride lots was trivial compared to the overall needs of California transit in the years ahead in relation to small transit vehicles and essential public mobility services. As COVID-19 made riding in close proximity with strangers more risky, a need for more fundamental changes in transit operations became clear.

Following discussions with Caltrans, the research focus was revised to study public ride services feeding not only high-capacity fixed route transit stations, but anywhere that essential trips are required by people without other options, especially in locations not served by existing fixed route transit. In addition, if on-demand service could replace low-productivity fixed route transit for any destination in a defined service zone, such a change would be worth considering.

Some transit users switching to automobile use during the pandemic suggests that revising transit services to compete by providing a higher quality, curb-to-curb, on-demand service, may be necessary to win back customers when general immunity from COVID takes hold. On-demand services implemented in the near term also provide the initial configuration for determining whether a more cost-effective version using driverless automated control could reduce operating costs in the long term.

VTA's pioneering FLEX microtransit pilot service in 2016 showed that if reduced operating costs and higher boardings per hour could be achieved, general purpose, on-demand transit could cost-effectively replace fixed route bus service with low ridership. Microtransit provides a bridge to recovery when the pandemic eases, even if the recovery takes several years.

Analysis of the 2019 performance measurements for California public transit in the National Transit Database (NTD) suggests that microtransit is a viable strategy where fixed route productivity is low.

The current environment is also an opportunity to gain economies of scale, by unifying small vehicle mobility services across urban travel markets, a recommendation of the Federal Coordinating Council on Access and Mobility. For example, experience in a few locations already demonstrates that paratransit for the disabled can potentially be combined generally with non-emergency medical transport (NEMT) and the many other categories of the mobility disadvantaged market defined by government planners, including seniors, youth, low-income households, and non-car-drivers.

One path forward for transforming public transit is to convert the least productive fixed route services into pilot implementations of computer-dispatched, on-demand general purpose microtransit services. These services should be managed with consideration of future conversion back to scheduled, fixed route alternatives if demand grows sufficiently to meet productivity and travel time standards.

With technical support from a state-level service bureau, changes in transit service toward more on-demand dispatching of smaller vehicles can be evaluated in advance of implementation with simulations using digital twins of the deployed networks. Such simulations would provide agency officials with understanding of the performance implications of service alternatives, as well as forecasts of the impacts resulting from changes in population and land use. This report also discusses the conditions for integration of both private sector taxis and wireless ride-hail vehicles into a microtransit system for expanded coverage in periods of low demand.

In summary, the research described here explores the practicality of serving as many customer markets as affordable and sustainable with COVID-safe small vehicle services. These services would be available on demand, within a few minutes of the specific time needed, day or night, to reach both rail and bus stations, as well as other destinations that are not better served by transferring to a trunk line.

1. Introduction

Park-and-ride (PnR) facilities provided by the California Department of Transportation (Caltrans) and public transit agencies like Bay Area Rapid Transit (BART), Santa Clara Valley Transportation Authority (VTA) and the commuter rail line Caltrain, provide access to transit for households not located close to high capacity transit routes, linking workers and students to employment and educational locations. PnR facilities allow transit customers to solve the residential end (morning origination and evening destination) of the so-called first and last mile problem by using their own private vehicles.

As described by Niles and Pogodzinski, statistical analysis of agency records in San José and Los Angeles shows that parking near transit stops has a larger positive marginal influence on transit ridership than housing density near transit stops.[1] The influence of 100 park-and-ride spaces on morning weekday transit ridership is 2.4 times that of 100 near-transit housing units for VTA and 1.9 times for Los Angeles Metro. These quantitative results along with additional evidence in the cited report suggest that PnR facilities are likely to be an ongoing strong source of ridership.

Nevertheless, PnR facilities have in recent years fallen out of favor with transit planners in those two cities. Over the past few years, these transit agencies have considered alternative uses of station-adjacent land devoted to parking. A leading alternative is re-purposing of parking facilities into housing, both market level and subsidized affordable. This repurposing achieves two goals: (a) it signals a public interest in finding ways for customers to reach transit that do not generate vehicle miles traveled (VMT), such as walking, cycling, and scooters; and (b) it improves the financial condition of the agency by reducing the costs of maintaining parking, while at the same time generating real estate revenue through sale or lease of land near stations.

The light rail network of the VTA—Silicon Valley's public transit agency—was chosen for a case study because of its proximity to the Ride & Ride research team's home base at San José State University and their familiarity with this system from previous research. VTA seeks to reduce parking around light rail stations for several reasons, including both state and local government policies to reduce single occupant vehicle (SOV) car driving in the region and the transit agency's interest in repurposing a portion of park-and-ride spaces into transit-oriented development (TOD) projects.

It is the VTA agency judgment that supporting TOD at light rail transit stations provides opportunities for revenue generating opportunities that justifies reducing the size of parking facilities. Indeed, many of these facilities were not full even before the pandemic (Table 1).

Table 1. Survey of Park-and-Ride Capacity Utilization at VTA, August 20–22, 2019

Location	Parking Spaces	City	% Full
Winchester Station	54	Campbell	100%
Tamien Station	369	San José	98%
Hostetter	100	San José	82%
Cottle Road Station	421	San José	80%
Alum Rock Transit Center	110	San José	79%
Great Mall	93	Milpitas	72%
Bascom Station	112	San José	68%
Evelyn	205	Closed	62%
Whisman Station	58	Mtn View	62%
Penitenica Creek	53	San José	49%
Moffett Park	102	Sunnyvale	44%
Blossom Hill Station	481	San José	39%
Ohlone/Chynoweth Station	549	San José	34%
Almaden Station	189	San José	30%
I 880 / Milpitas	275	Milpitas	27%
Branham Station	271	San José	20%
Snell Station	430	San José	19%
Capitol Station	951	San José	17%
Santa Teresa Station	1155	San José	17%
Curtner Station	447	San José	17%

Source: VTA spreadsheet provided to the Ride & Ride research team, July 22, 2020

The original intent of the Mineta Transportation Institute Ride-and-Ride research project was to assess alternative publicly supported ride services that would be attractive alternatives for urban commuters who use park-and-ride lots at the nearest station. However, due to the onset of the 2020 pandemic, these questions became too narrow given the breadth and depth of the performance problems in California transit.

2. Revising the Research Focus

In March 2020, the COVID-19 pandemic began and affected all public transit agencies in California as illustrated in Table 2. Public health rules and travelers' caution resulted in transit agencies quickly losing more than half of daily ridership in 2020, which created financial pressure due to a drop in revenue from both fares and taxes.

Table 2. Transit Boarding in California, Aggregated for All Agencies in Urbanized Areas Defined by the U.S. Census

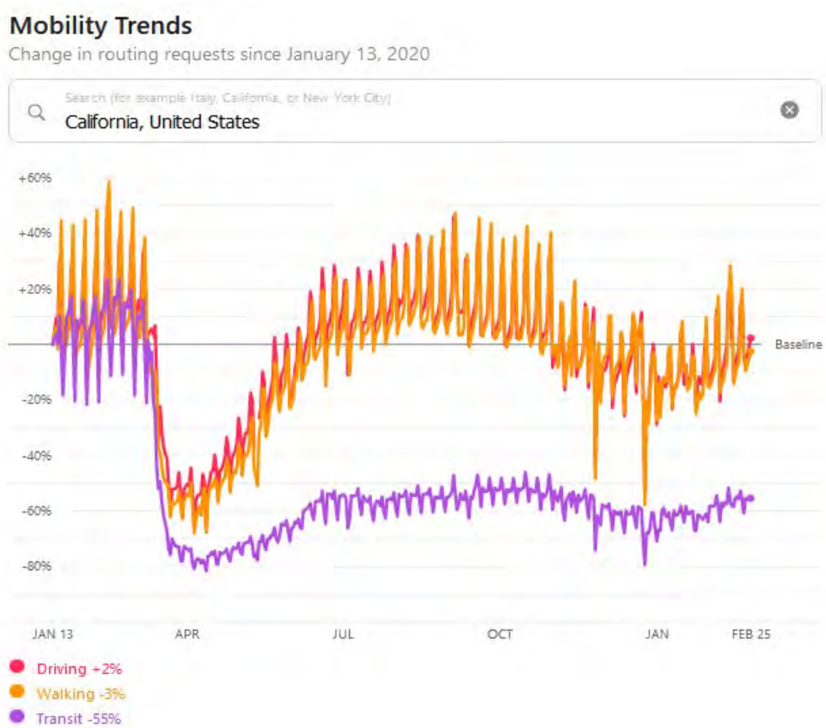
Urbanized Area	2019 Boardings (All Year)	2020 Boardings (Through Oct)	2020 vs 2019 (Jan to Oct)	2019 vs 2010 (All Year)
LA - LB - Anaheim	528,384,941	255,476,995	-42.6%	-20.3%
SF - Oakland	444,354,812	150,766,482	-59.7%	7.0%
San Diego	98,870,971	45,630,812	-45.2%	2.7%
San Jose	36,242,147	14,056,883	-47.2%	-13.4%
Sacramento	24,407,075	10,607,724	-47.6%	-26.7%
Riverside-SB	19,966,347	8,864,856	-53.7%	-14.3%
Fresno	10,850,172	5,492,575	-39.6%	-16.8%
Santa Barbara	6,551,089	2,710,007	-54.5%	5.3%
Bakersfield	6,315,047	3,017,708	-41.6%	-10.1%
Concord	5,469,051	2,064,406	-51.0%	16.0%
Stockton	5,461,305	2,239,053	-41.6%	-3.1%
Oxnard	4,365,062	2,132,058	-38.0%	-23.6%
Indio-Cathedral City	4,236,825	2,169,074	-38.7%	7.5%
Santa Rosa	3,547,295	1,461,498	-51.6%	-11.5%
Santa Clarita	2,622,536	1,302,228	-41.8%	49.6%
Lancaster-Palmdale	2,436,225	1,000,352	-50.5%	-17.4%
Modesto	2,393,829	1,263,222	-41.2%	-24.6%
Victorville-Hesperia	2,325,747	1,134,526	-41.7%	-33.0%
Antioch	1,855,704	925,408	-40.1%	-1.3%
Visalia	1,554,410	791,739	-50.7%	-15.3%
TOTAL	1,212,210,590	513,107,606	-49.7%	-9.5%

Source: National Transit Database

Boardings were down between 38% and 60% through October 2020 compared to the same ten-month period in 2019 for all California cities. The total loss in ridership was 50%. This ridership loss was on top of overall ridership losses in the years 2010 through 2019.

Ridership in California has not recovered significantly in 2020 and did not improve through February 25, 2021, as seen in the purple line in Figure 1 from Apple Maps Mobility Trends Reports that presents the changes in iPhone requests—reflecting ridership levels—for transit route information across the entire State of California relative to a January 2020 pre-pandemic baseline.[2]

Figure 1. Post-COVID-19 Transportation Mode Use, State of California



Note: A comparison of the usage of three transportation modes (driving, walking and transit) as gathered through iPhone data, from January 2020 (pre-pandemic) to February 2021 (during pandemic). Percent changes in driving shown in red, walking in orange and transit use in purple.
Source: https://covid19.apple.com/mobility

Different funding sources experienced different impacts from decreased ridership. Agencies that rely on sales taxes did not suffer because California's sales taxes increased during the pandemic. Revenue from parking meters and transit occupancy taxes from hotels experienced large drops, which negatively impacted agencies like the City and County of San Francisco Municipal Transit Agency that relied heavily on them. Apart from revenue, operator availability was a large issue in the early months of the pandemic, which resulted in decreased service levels.[3]

Decreases in tax revenue is the more serious issue, as farebox coverage in previous years accounts for only 23% of operating expenses statewide and just 9% for VTA, according to the NTD.

The continued depression of transit trips in comparison to car trips, as pre-pandemic mobility resumes, demonstrates that a general decline in need or ability to travel is not the only issue. The loss of ridership is amplified by consumer awareness of the dynamic of airborne transmission of the COVID-19 virus, which is the most significant means by which the illness spreads in a population.[4] Social distancing, an important tactic for avoiding illness, is supported by transit agency rules limiting the number of passengers in vehicles.[5,6] Limits on passenger loads have also been established by private sector passenger service operators such as Uber, Lyft, and Via.[7]

Consumer surveys indicate that fear of being in a vehicle with infected individuals may be an issue throughout 2021 and possibly beyond.[8] A study by municipal bond analysts at Moody's Public Sector Europe examined public transit in London, Paris, New York City, and Vancouver, British Columbia. This research forecasts a permanent 20% drop in ridership post pandemic from all causes, including dispersion of work sites to homes and other locations not in established transit destinations such as downtowns.[9] The conclusions and recommendations in this present report are predicated upon the assumption that post pandemic ridership is expected to be lower.

The risk to future ridership was emphasized in the March 22, 2021 Final Draft Problem Statement of the Bay Area Metropolitan Transportation Commission's Blue Ribbon Transit Recovery Task Force:

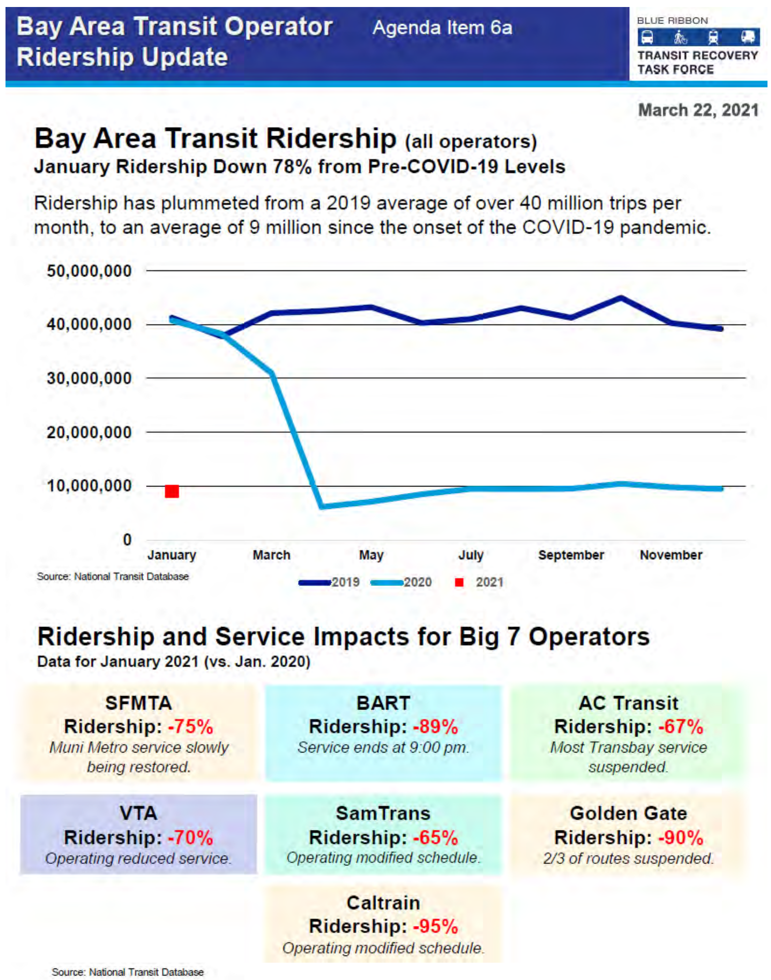
> *The COVID-19 Pandemic has dramatically reduced the ridership of the Bay Area's transit system—and it is unclear when, and to what extent, ridership will return. In the near-term, the pandemic has created an acute, existential crisis for transit; however this only underscores and deepens the pre-existing problem of declining demand for transit in the region as a whole. If sustained, this decline in ridership threatens to plunge the region's transit system into a downward spiral, jeopardizing both the near- and long-term financial viability of individual transit operators and negatively impacting riders.*[10]

This same Blue Ribbon Task Force put on record the Bay Area's devastated transit ridership, as shown in Figure 2, approaching one full year of pandemic-induced suppression as of January 2021.

In addition to the awareness given to providing safe ridership from a public health perspective, the pandemic's falling ridership motivates renewed attention on how transit can contribute to mobility sufficiently to justify the taxpayer investment. This in turn leads to the question: what are the missions and markets for transit to focus on serving?

Traditional, legacy transit missions include the following two items. First, government funded public mobility provisions for urban efficiency is important. Public transit in the densest urban zones amounts to a societal response to limited street capacity and sometimes limited parking capacity. Transit service reduces the need to continue adding parking and road lane infrastructure in dense employment centers by reducing the frequency with which commuters and visitors choose to use their private vehicles.

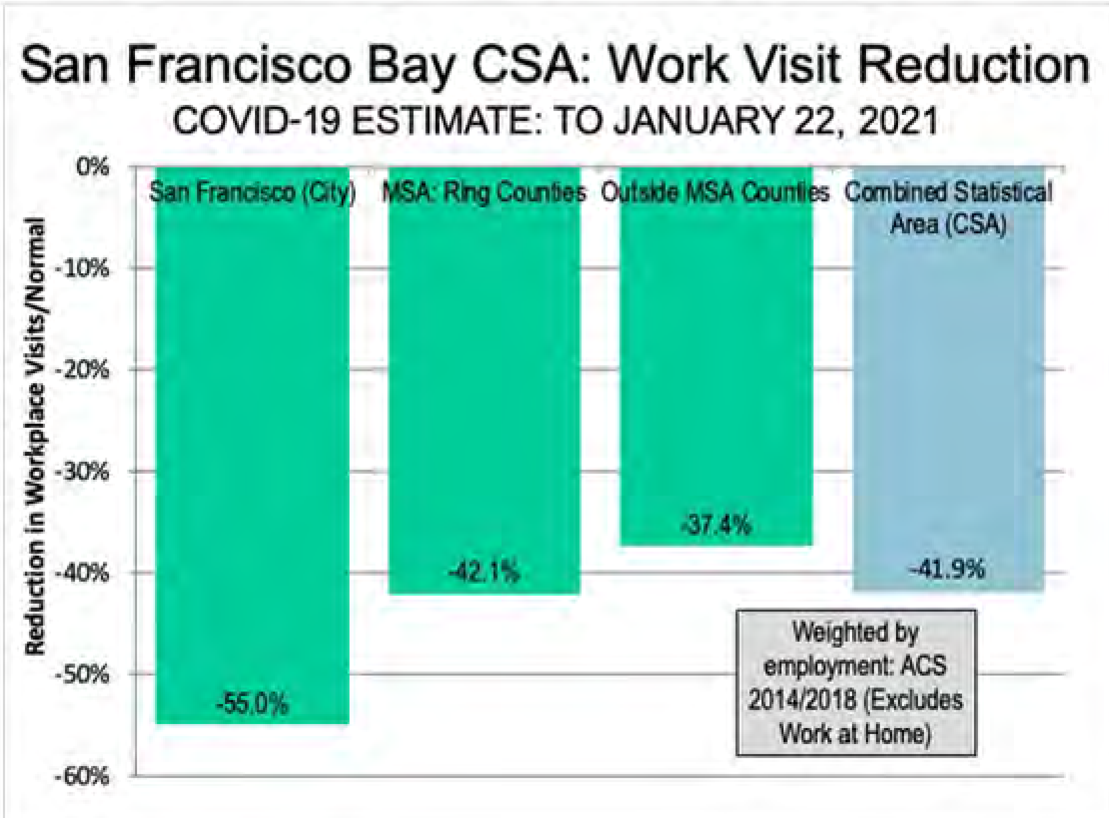
Figure 2. California Bay Area Transit Ridership in 2020 Compared to Pre-Pandemic (upper panel) and Ridership Impacts by Service Provider (lower panel) 2019



Source: Record of the March 22, 2021 meeting of Bay Area Transit Recovery Task Force

However, during the 2020 pandemic, travel to work locations in the densest parts of metropolitan regions fell dramatically, as illustrated in Figure 3, showing the reduction between January 2020 and January 2021 in the San Francisco Combined Statistical Area (CSA).[11] Work trips fell by 42% across the entire CSA and by 55% in San Francisco. As of April 2021, there are indications in survey evidence that work trips to employment centers in California may continue to be depressed below pre-pandemic levels as work-at-home patterns become more institutionalized.[12]

Figure 3. Reduction in Non-Residential Work Visits during the Pandemic for the San Francisco Bay Area Geographic Regions



Source: Derived from Google Mobility Reports and American Community Survey data by Demographia for NewGeography.com, https://www.newgeography.com/content/006930-work-trips-csas-with-largest-cbds

Another reason for public interest in expanding transit use, especially in California, is to reduce greenhouse gases (GHG) and improve local air quality. Promotion of transit use and transit-oriented development (TOD) reduces solo driving and thus reduces emissions. The public policy of the California State Transportation Agency is to push for more transit ridership.[13] However, this choice of transportation mode was declining before the pandemic (Table 2), and during the pandemic, transit use became even less appealing. Fortunately, the use of low-emissions vehicle-power technology across all public and private vehicles is a stronger, more universal force for emissions reduction than mode shift toward greater use of public transit, and there is a trend toward electrification of household vehicles and public transit vehicles, motivated by public policy.[14]

While the first two justifications for public transit are diminished as ridership drops, a third reason for public transit, supporting essential trips for people without private mobility, has risen to the top of the priority hierarchy. This critical and rising focus is discussed in the next section.

3. Serving the Mobility Disadvantaged

The experience of the pandemic has placed greater emphasis on public transit's long-standing mission to provide a mobility option for poor or physically disabled individuals as well as people without cars or other affordable, reasonable transportation alternatives.

Essential workers without private mobility options—including those working in health care, public safety, and retail stores providing food, cleaning supplies, and medications—need and want an affordable commute to their jobs, often outside of regular commuting hours. This has become an increasingly urgent issue in the pandemic.[15]

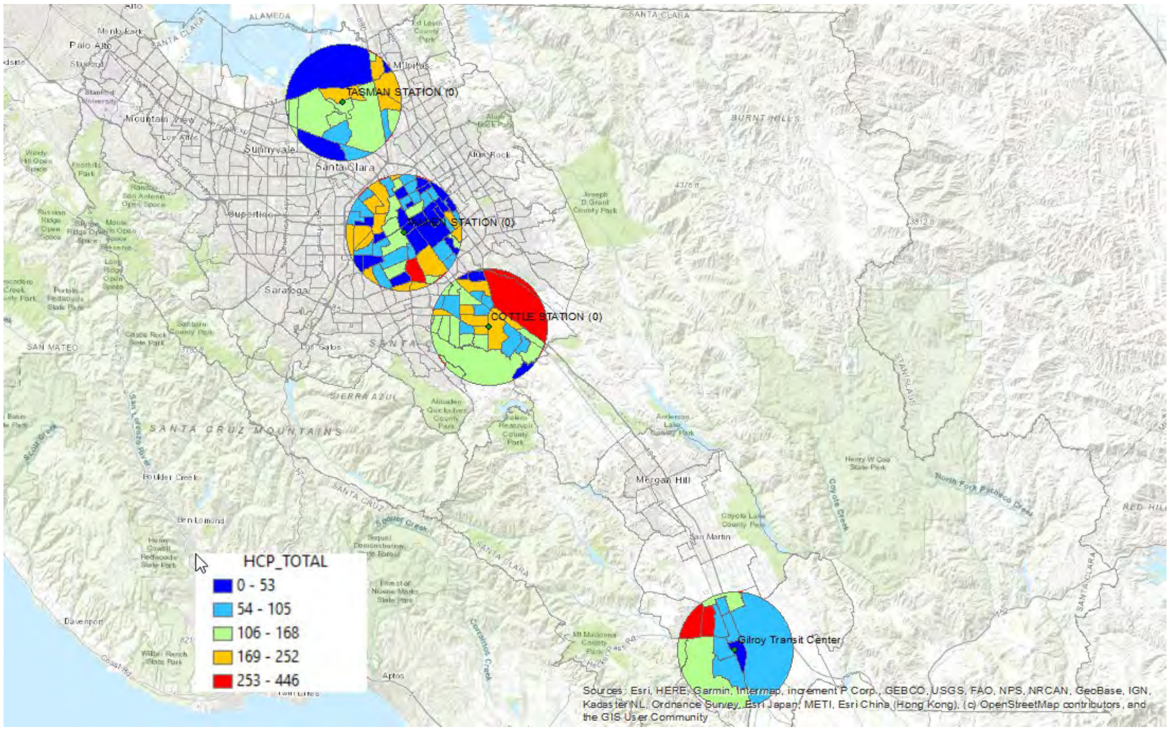
Research by Liu et al. concluded:

> *[C]ities with more essential workers and a more vulnerable population tend to maintain higher transit demand levels during COVID-19. This moreover suggests the necessity of the transit system during a pandemic when transit systems lose a great deal of discretionary demand. This should motivate transit planners, policy makers, political leaders, and taxpayers to rethink the role of transit systems not as a business, but as critical infrastructure for a community.*[16]

VTA staff indicated to the Ride & Ride research team that transit agencies operate a calculated combination of ridership-purposed routes and coverage-purposed routes to create the most useful community infrastructure.[17] Geographic Information Systems (GIS) data and mapping software can be used to identify neighborhoods where a relatively high number of people in mobility disadvantaged groups live and contribute to the analysis of how changes in access schemes influences ridership. For example, the map shown in Figure 4 illustrates the distribution of health care workers in three-mile catchments around selected transit stations in Santa Clara County. Red and orange regions indicate where the number of people in this occupational group is higher. Section 16 of this report, Simulation Tools, describes a circumstance in which demographic information in GIS formats can be used as part of future transit system management.

The researchers examined several distinct categories of the mobility disadvantaged population in a three-mile radius around a sample of VTA light rail stops and the Gilroy Transit Center, where an express bus runs north in the morning to downtown San José (Table 3). Larger numbers in this table indicate larger potential influence on ridership from the associated characteristics in the transit-adjacent population. Two examples of using demographic data of potential riders to discern the importance of transit to the mobility disadvantaged are described next.

Figure 4. Numbers of Health Care Workers Living around Selected VTA Transit Stations



Note: Red indicates high values; blue indicates low values.
Source: Estimates by Mineta Ride & Ride research team based on indicated buffer distance using American Community Survey 2018 data

Table 3. Exploring Demographics within Three Miles of Selected VTA Transit Stations

		Estimated number of each group residing within 3 miles of a given station						
Name of station	Weekday LRT or express bus boardings	Population	Senior	Disabled	Below poverty level	Health care workers	Trans-portation workers	House-holds with no vehicles
Gilroy Transit Center	231	47,577	7,196	4,157	4,901	2,104	725	330
Cottle Station	330	137,051	23,820	11,276	9,843	6,299	1,566	1,340
Tamien Station	466	264,313	42,802	24,008	32,240	9,979	3,379	4,084
Tasman Station	209	91,968	10,782	5,161	6,877	3,225	1,101	1,638
	As a ratio to total population in the 3 mile radius zone							
Gilroy Transit Center	0.49%	100%	15.1%	8.7%	10.3%	4.4%	1.5%	0.7%
Cottle Station	0.24%	100%	17.4%	8.2%	7.2%	4.6%	1.1%	1.0%
Tamien Station	0.18%	100%	16.2%	9.1%	12.2%	3.8%	1.3%	1.5%
Tasman Station	0.23%	100%	11.7%	5.6%	7.5%	3.5%	1.2%	1.8%

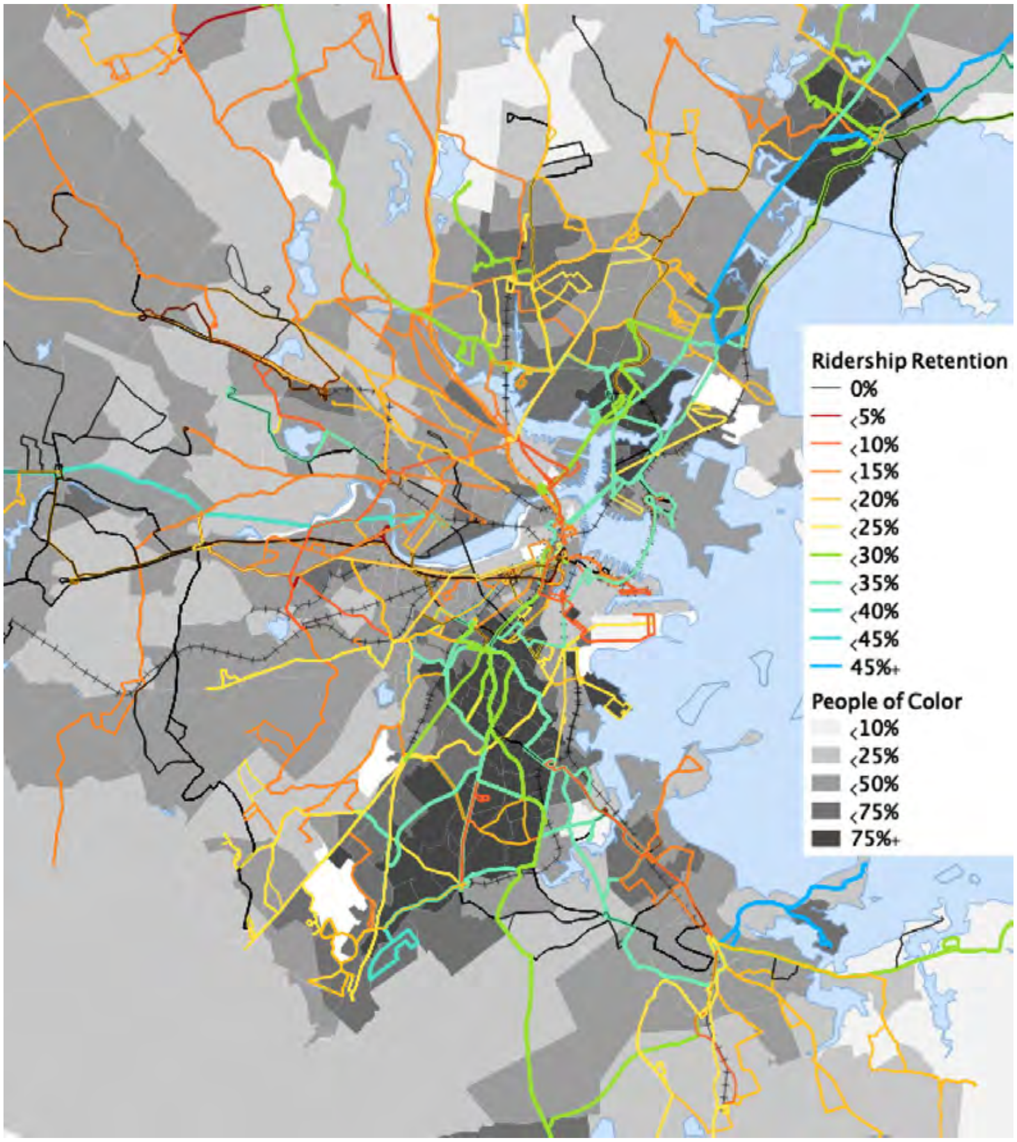
Source: American Community Survey for demographics; VTA for 2020 transit boarding at https://public.tableau.com/profile/janice.soriano#!/vizhome/SystemwideRidershipbyStop/Dashboard1

The first example, shown in Figure 5, comes from the public interest foundation and research group TransitCenter, which demonstrates an urban transit agency retaining ridership from the mobility disadvantaged during the pandemic. Their research report about the experience of the Massachusetts Bay Transportation Authority (MBTA) in Boston examined ridership changes by bus route:

> *Another way to visualize these shifts is to look at ridership changes by route. The average MBTA bus route retained 15% of its ridership from spring 2019 to spring 2020, and most routes through affluent western suburbs retained even fewer riders. But high-ridership bus routes that serve communities of color and low-income neighborhoods to the south and northeast [darkest gray on the map below] retained more than 30% of typical ridership. The routes with the highest ridership retention rate—above 40%—connect suburbs on the periphery to the central city.*[18]

Note that these conclusions are coming from the demographics of the geographic zones where commuting workers originated, not from on-board transit ridership surveys.

Figure 5. Weekday Boston Bus Route Ridership Retention in 2020 as Percentage of 2019 Ridership; Areas Indicated with Various Percentages of People of Color



Source: TransitCenter

In a representative nationwide U.S. sample survey of 1,302 transit users by Parker et al.[19] in 2020, the 216 (17%) who were affected by transit service cuts showed a higher level of mobility disadvantage than those who were not affected (Table 4).

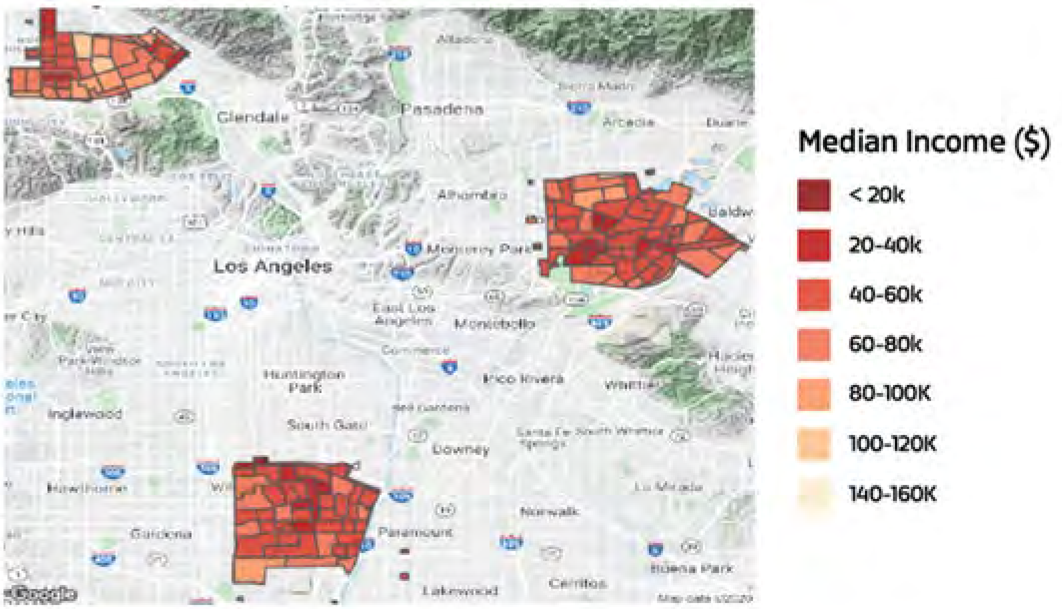
Table 4. Correlation of Mobility Disadvantage with Transit Impacts

	Affected by transit cuts	Not affected by transit cuts
Decreased income in pandemic	67%	45%
No household vehicle access	24%	9%
Person of color	68%	47%

Source: Parker et al. 2020, https://home.hiroshima-u.ac.jp/~zjy/international-e-conference-on-pandemics-transport-policy/

The importance of deploying transit to the mobility disadvantaged is illustrated by a second example: a pilot implementation in Los Angeles of on-demand microtransit to customers from lower income neighborhoods. Via, Inc., a private microtransit, mobility-on-demand ride provider, working under contract for Los Angeles County Metro Transit, operated this service. An evaluation project counted and characterized the economic status of riders using the small vehicle service, based on the median household income of the area of their boarding, in the three neighborhoods shown in Figure 6. In the period from January to July 2020 the effect of COVID-19 on ridership was measured by counting boarding levels over time as the pandemic evolved. The 100% level on the line graph in Figure 7 represents the pre-COVID patronage peak from 2019. The three lines divide riders into three household income levels. The graphs show the steep drop in March as the pandemic began, and then the recovery that began by April 1 and continued through July. The lowest income group—$40,000 per year and below—recovered to 2019 levels and then exceeded that to a greater degree than the higher income riders. The vendor noted that this result was achieved by LA Metro responding to the pandemic by extending hours of service and offering curb to curb trips to any destination within the zone instead of just transfer points for fixed route service. Furthermore, the service zones were expanded to include hospitals and a few other locations deemed important for commuters employed in essential work.[20]

Figure 6. Three LA County Metro Microtransit Service Zones in Los Angeles
with Median Income Indicated



Source: Reported by Via, https://meetingoftheminds.org/new-data-suggests-on-demand-transit-is-essential-for-equity-34051

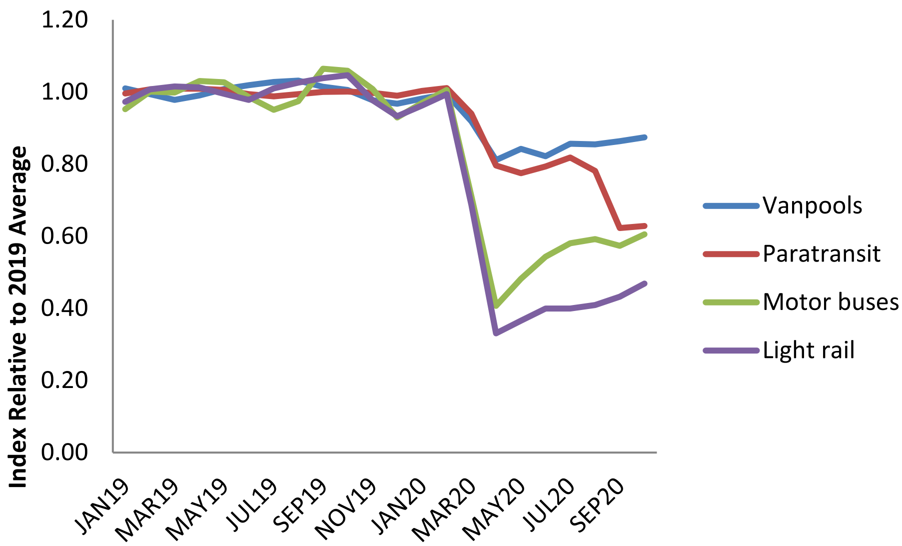
This example suggests that there is a readily available solution to support the travel requirements of mobility disadvantaged residents: the deployment of small transit vehicles running on existing roads to the neighborhoods where people in this demographic reside. Furthermore, these maps show that identifying the neighborhoods most needing mobility services can be recognized through American Community Survey data, such as that shown previously for VTA light rail stops.

Figure 7. Recovery of Microtransit Ride Request Volumes in 2020 by Income as the Pandemic Continued

Source: Reported by Via, https://meetingoftheminds.org/new-data-suggests-on-demand-transit-is-essential-for-equity-34051

An important related observation from the NTD statistics indicates that across the U.S. during the pandemic, van-sized transit vehicles of vanpools and paratransit in 2020 are holding onto passenger loads better than larger vehicles of bus routes and light rail lines, as shown in Figure 8. This comports with the public health guidance that small groups in vehicles are less risky than large groups, in efforts to stem infections.[21]

Figure 8. Performance of Different Vehicle Sizes in Maintaining Pre-Pandemic Passenger Loads from Jan 2019–Sep 2020

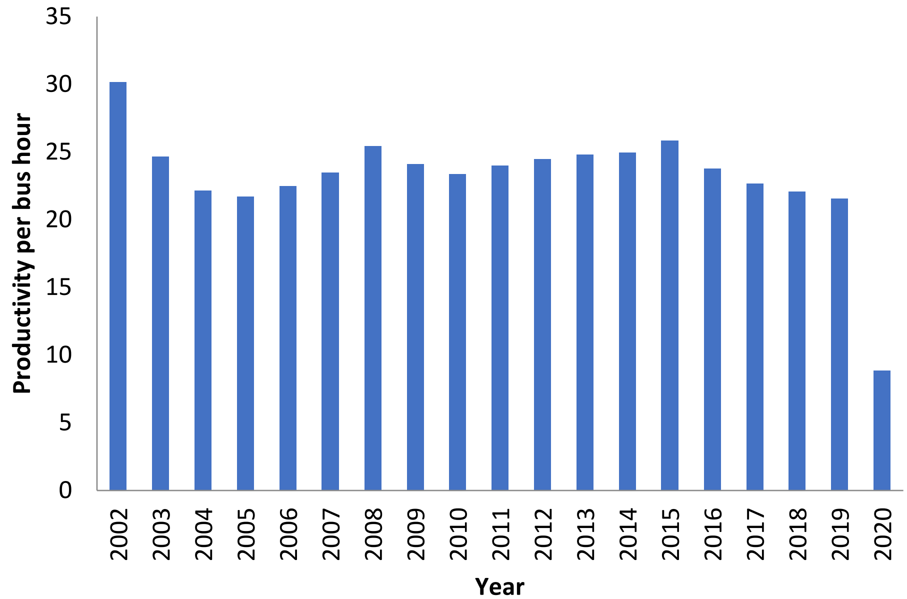


Note: Vanpools are indicated in blue, Paratransit in red, buses in green and light rail in purple.
Source: National Transit Database showing boardings per vehicle mile indexed to 2019 average.

These considerations stimulated the Ride & Ride research team to expand their project scope beyond just first and last mile access to stations, into an examination of extending the reach of transit, while trying to maintain productivity levels, measured in cost per boarding or boarding per vehicle hour of revenue service.[22] These productivity metrics are specified in detail by the Federal Transit Administration (FTA) reporting requirements in order to maintain comparability between fixed route and on-demand services.[23] The team investigated the possibility of enhancing service quality across more trip purposes than just those of car-owning transit customers. At the same time, the researchers examined extending service into areas not served by fixed route bus lines.

Productivity of fixed route bus service has fallen at VTA in recent years, and tumbled further in the pandemic, as shown in Figure 9.

Figure 9. Productivity per Bus Vehicle Hour at VTA from 2002 to 2020



Note: Productivity per bus vehicle hour is in decline from 2015.
Source: National Transit Database

It is important to emphasize that the results described here did not employ the deep consultation process that is required to support making recommendations to VTA. Furthermore this was not the purpose of the research; the goal here is to stimulate new ideas and set a new direction for all public transit in California.

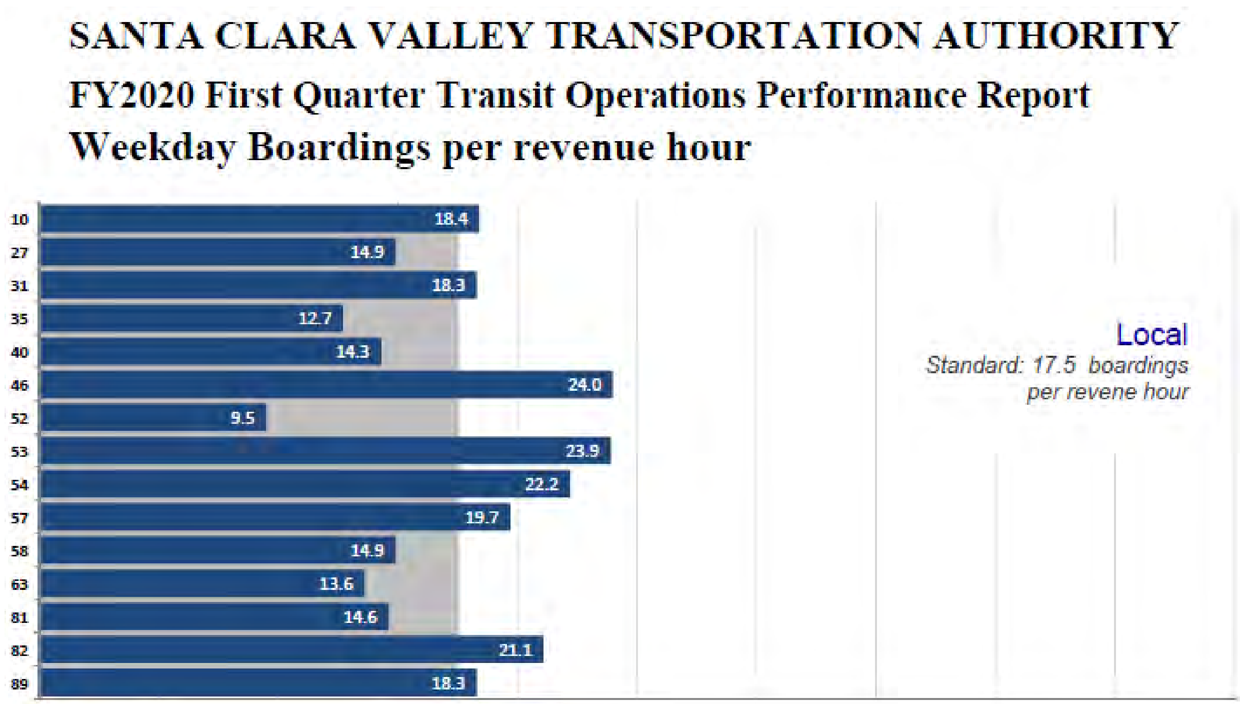
The Ride & Ride research team sought to assemble ideas for action considered by other transit agencies across North America, as described in the Recommendations for California Transit, Section 18.

Even before the 2020–21 pandemic, public transit agencies in California and nationwide had been experiencing deteriorating ridership and rising costs per boarding, per passenger mile, and per revenue service hour. The number of bus boardings per vehicle hour is illustrated for VTA in Figure 9, the result of suburbanizing land use characterized by sprawling employment sites, widely dispersing consumer service locations, and the continuing popularity of driving. Surveys conducted by the U.S. Census and others find that the majority of low-income households choose automobile travel over transit; for example, Table 5 shows the transportation mode share for commuting to work in the San José metropolitan area. Senior citizens are driving more than ever, and increasingly safely.[24]

Using data on ridership and operating costs provided by VTA, the researchers examined several existing fixed route bus services. Examples of the performance variation are shown in Figure 10 for one category of bus routes. Based on alternative transit arrangements deployed in other cities, the researchers examined—for illustrative purposes—portions of some more lightly patronized VTA fixed route local bus services that are trunk station feeders. It was hypothesized that some of these could be converted to on-demand service at a cost savings with ridership and service improved.

On-demand services could be made compatible with the public health requirements for controlling the spread of infection by configuring vehicles for safe passenger loading in well-ventilated compartments, with required passenger face covering, support of contact tracing, and anti-viral cleaning of both touchable surfaces and the interior air that passengers breathe, as described later in Section 17.

Figure 10. Productivity as Measured by Boardings per Revenue Hour Varies across Bus Routes of VTA



Note: This method of measuring productivity is typical for public transit agencies.
Source: "VTA Transit Operations Performance Report, FY2020 First Quarter Report," http://santaclaravta.iqm2.com/Citizens/FileOpen.aspx?Type=4&ID=9243

As shown in Section 11, simulations undertaken by Via suggested that any origin-destination pair within a specified service zone—typically five to seven square miles—could be served for the same cost as a fixed route service with a standard-sized bus that is not carrying sufficient riders to meet efficient levels of boardings per service hour.

VTA had earlier piloted an on-demand service in the first six months of 2016 called Flex (described below in Section 8) that turned out to be too expensive per rider to be continued.

4. Operational Productivity and Geographic Coverage

There is an important relationship between geographic coverage and operational productivity. Fixed route transit is most productive when scheduled transit routes serve dense population or employment zones along an entire route corridor, or at one end of the route, typically the morning destination of employment centers. Stations for commuters to assemble and board transit provide virtual density and operational economies of scale at the morning origin points. Coverage of less dense areas with traditional fixed route service yields lower numbers of boardings per service hour, which results in lower productivity.

A standard way to increase productivity of transit service is to establish park and ride (PnR) facilities at outlying parts of the fixed route network. PnR facilities serve to aggregate riders so that transit can serve low density suburbs with greater efficiency. Supplementing the transit network with customer provided movement to rider collection points at the network edge reinforces network scale economies. As pointed out by Reid Ewing, "…the service area for a transit station or stop with a park-and-ride facility is on the order of 400 times greater than the service area based on walk access alone."[25] Ewing's geometric calculation corresponds precisely to comparing a typical quarter mile nominal walking range for a bus stop to a five-mile vehicle movement radius around a PnR access point for transit customers.

Niles and Pogodzinski conducted a study showing that park-and-ride facilities yield increased productivity in bus operations compared to extending fixed routes into lower density suburbs. They analyzed 53 Seattle Eastside suburban bus routes and found that in 2015 50,000 transit service hours (worth $17 million, ten percent of the operating expenditures for this suburban zone) were saved in 2015 because of the bus passenger who are picked up at PnR facilities instead of at non-PnR bus stops.[26]

On demand, small vehicle transit attempts to improve productivity by using smaller vehicles with lower operating costs and driving directly to where customers are waiting to board, having signaled in advance via phone or computer app when they would be at the stop, ready to board. A portion of the lower operating cost in smaller, van-sized vehicles can come from employing less-skilled and lower-paid vehicle operators because of no requirement to drive forty foot and larger coaches.

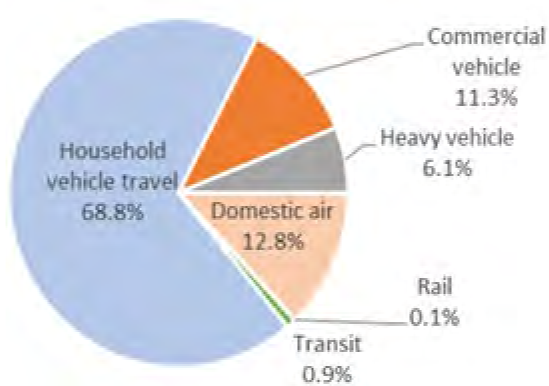
This research explores the prospect of low-productivity fixed route service in low density customer zones being replaced by on-demand service that provides better service at the same or lower cost per rider than lightly loaded fixed route buses. In other words, an efficient way to improve service now being provided by a fixed route bus picking up nine passenger per hour at bus stops may be to replace it with three on-demand vans picking up riders at or near their homes at the rate of three passengers per hour.

5. Strength of Automobility

Serving complete trips, from the doorway, or at least the curb, of the departure point to the front door or curb location of the destination, is a priority established by the U.S. Department of Transportation (USDOT) for senior, disabled, and low-income travelers. As described by the USDOT, "The concept of a complete trip is that an individual can travel from origin to destination without gaps in the travel chain. A complete trip includes multiple links or trip segments. If one segment of the trip is inaccessible, unreliable, or inefficient, then the trip cannot be completed."[27] This priority is directly relevant to the providing first and last mile service for those not close to train and bus transit stops. The USDOT focuses its Complete Trips funding program on improvements that serve the mobility disadvantaged, defined in this program as "people with disabilities, older adults, low-income individuals, rural residents, veterans, and limited English proficiency travelers."[28] However, the complete trip concept is arguably important for all customers. One idea of complete trips is focused on making transfers between vehicles, when necessary, easy and convenient.

The most popular motorized mobility machine for complete trips in the U.S. is the private automobile, although not available for all travelers, especially those who are not able to drive, or who do not have another driver with a car in the household, or who just cannot afford this mode. Figure 11 compiled by Polzin for USDOT shows the dominance of private household vehicles in the overall transportation mode split across all U.S. travel in 2019.

Figure 11. Annual Estimated U.S. Person Miles of Travel by Mode in 2019



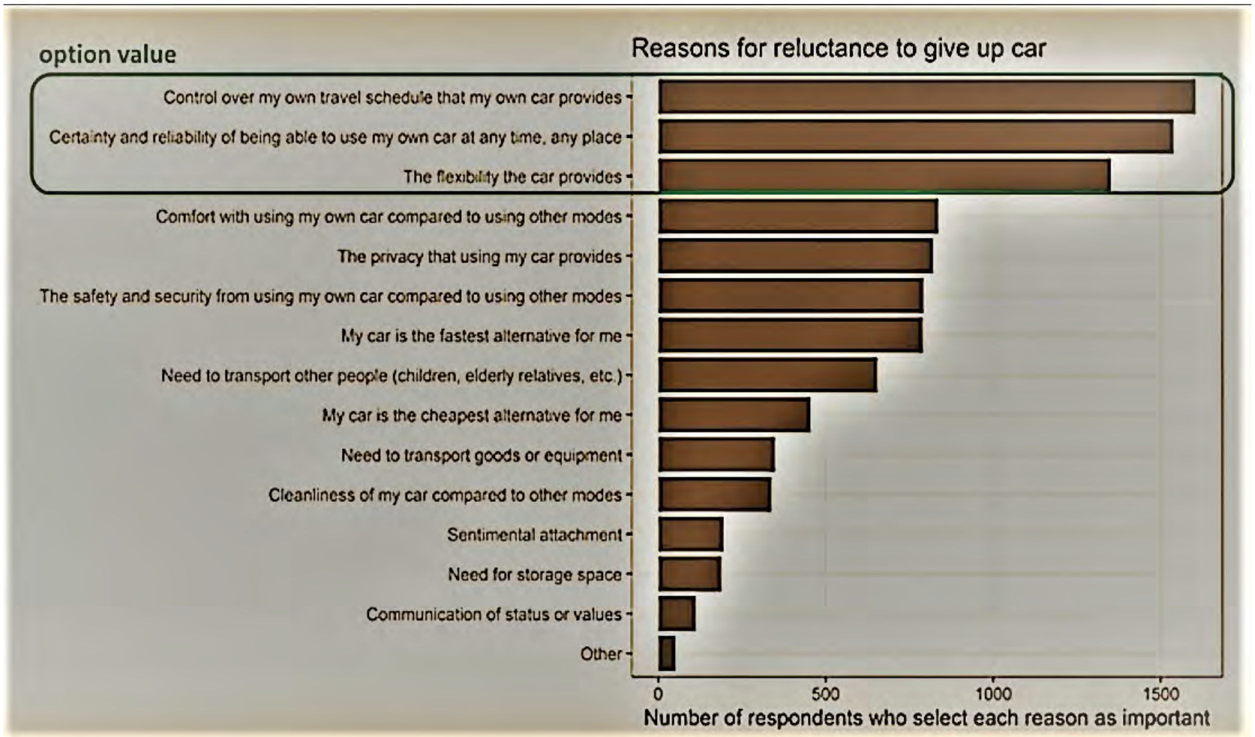
Note: compiled by USDOT headquarters staff based on a synthesis of data from the Bureau of Transportation Statistics and National Household Transportation Survey.
Source: Steven Polzin and Tony Choi, "COVID-19's Effects on The Future of Transportation," Office of the Assistant Secretary for Research and Technology, January 14, 2021, https://rosap.ntl.bts.gov/view/dot/54292

The well-known characteristics of private vehicle use explain its popularity:[29]

- On-demand, near instant availability
- Operator controlled, flexible routing and stops
- Operator controlled, flexible start and arrival times
- Door-to-door, any origin, any destination that roads reach
- Private, customized space while traveling
- Perceived safety and security
- Protection from the weather
- Ease of bringing family, friends, or cargo
- Emotional sensations related to control, style, and wealth.

Expanding on the last point, Joanna Moody at the MIT Mobility Systems Center recently conducted a survey that reveals private cars are valued more than they cost and the majority of that value comes from ownership rather than use. In a survey of 4,022 households in Dallas, Seattle, Chicago, and Washington, DC, in the pandemic summer of 2020 she found that the value of having the option of using a car when needed was more important than the superior characteristics of use compared to other modes like transit and Uber. This is somewhat less true in urban areas where alternative modes are available and used. However, overall, with regard to the pandemic, the survey respondents reported that the value of owning a car rose higher than the gain of value in actually using it. She defines "social status and personal image" from owning and using a car to be "car pride," and notes that it helps to explain why Americans put so much value on owning an underutilized asset.[30] Moody produced a chart shown in Figure 12 illustrating the predominance of option values over usage characteristics in attitudes toward private car ownership.

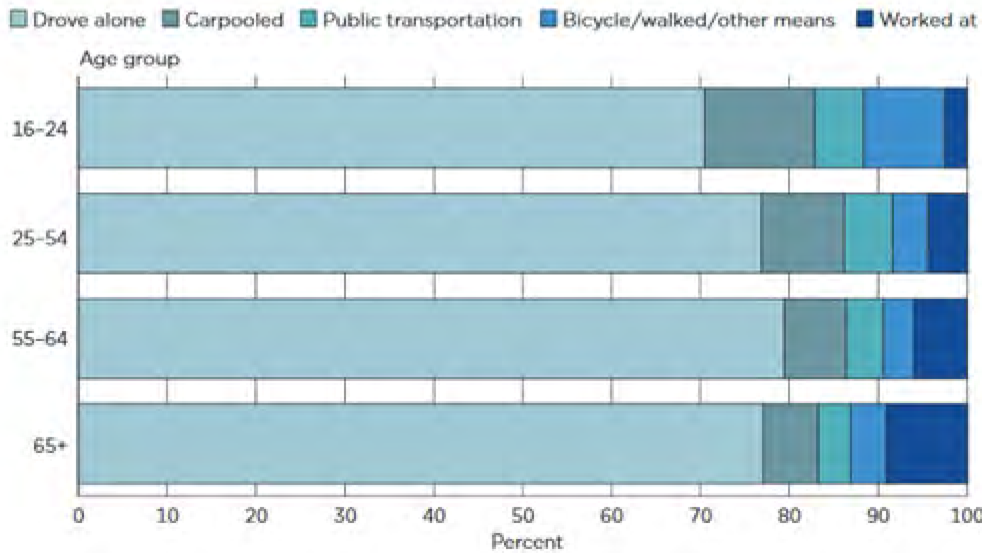
Figure 12. Valuing Private Car Ownership and Use in the U.S. Represented by Number of Survey Respondents who Identified Each Reason



Source: Webinar presentation by Joanna Moody

Travel to work by car or carpool is the massively dominant mode for all age groups, as shown in Figure 13.

Figure 13. Dominance of Car Travel Revealed by Percentage Distribution of Commute Travel Mode for Workers by Age



Source: U.S. Census American Community Survey, 5-year estimates, 2013–17[31]

The most recent commute trip data for California shows transit use in commuting is 10 percent or less for all but San Francisco in which transit achieves 30 to 40 percent share of commuting modes, being one of the densest urban regions in the United States, and the main focus of transit in the region, evidenced by the orientation of the BART heavy rail network to downtown San Francisco and Oakland, as illustrated in Figure 14.

Figure 14. Trends over Time for Transit Mode Share in Commuting, San Francisco Bay Area, 1960 to 2018

Source: Bay Area Metropolitan Transportation Commission, https://www.vitalsigns.mtc.ca.gov/commute-mode-choice#chart-1

Census data shows that commuting to work in the San José metro area occurs predominantly by automobile, as shown in Table 5. Even in the lowest household income category, the solo driving mode account for 67% of commutes. For all income categories, working at home occurs at a higher level than taking transit.

Table 5. Mode Share for Commuting to Work in San José Metropolitan Area

Household Income	$0 to $25K	$25K–$65K	$65K +
Solo driving	67.0%	77.3%	78.1%
Carpool-vanpool	13.2%	11.2%	8.7%
Transit	5.2%	3.3%	4.3%
Walk	4.2%	1.5%	1.2%
Taxi-Bike	3.9%	2.5%	3.0%
Work at Home	6.6%	4.2%	4.6%
TOTAL	100%	100%	100%
Ratio of Driving to Transit	15.5	27.0	20.1

Source: U.S. Census, American Community Survey, 2018 five-year estimates

In contrast to the transit mode share, automobile mode share continues to grow across many trip types, and the share has grown since the beginning of the COVID-19 pandemic. Fortunately, for the sake of regional air quality and lower emissions of greenhouse gases into the global atmosphere, the majority of car manufacturers are moving toward electric powered vehicles.[32] California's Governor has directed that "by 2035, all new cars and passenger trucks sold in California be zero-emission vehicles" on top of existing state incentives for zero emission vehicles.[33] On the safety front, car companies are adding automated driver assistance systems (ADAS) which measurably reduce crashes, as reported by the Insurance Institute for Highway Safety.[34]

Public policies for VMT reduction are in place in California and other states, but they are proving ineffective. Raising the price of driving and parking is the most reliable way to suppress VMT, but the advantages of flexible mobility are a strong incentive to keep driving.[35]

One well documented advantage is that cars provide much better access to employment opportunities than transit in urban areas from coast to coast, according to research at University of Minnesota Accessibility Observatory.[36] Using the same GIS-enabled methodology across the largest, most populous urban areas in the U.S., researchers calculated the number of jobs on average that a resident can reach by car and by transit in 30 minutes and 60 minutes. The ratio of transit accessibility to car accessibility as of 2015 in America's most transit rich metropolis, greater New York City, for 30-minute access is eight percent, and 19 percent for 60-minute commutes. This is the result of residential and job dispersion. The percentages are smaller in all other metro areas.

For example, San Francisco is at six percent for 30 minutes and 13 percent for 60 minutes. San José area residents experience the ratio of transit access to employment versus car access at two percent for 30 minutes and seven percent for 60-minute access.[37]

Furthermore, according to research with similar methodology from the same University of Minnesota Accessibility Observatory focused just on the Twin Cities metro area, found multimodal access through park and ride lots provides superior access to job sites compared to relying only on transit. Quoting a summary of this work, "Job accessibility is three times greater for those who can drive to park-and-ride facilities compared to those who walk to transit."[38]

The key characteristic of cars—taking trips from anywhere to anywhere, anytime, any day, with flexibility to change destinations and departure times at will without penalty—is highly desirable to households. That brings the transit discussion to mobility on demand.

6. Rise of Mobility on Demand

Since 2010 there has been greater growth in new urban mobility services for making trips on demand in comparison to those along fixed route transit lines. This kind of service is often called mobility on demand (MOD), or "shared" mobility if a ride service with multi-passenger vehicle loads is used. "Shared" also refers to serial use of short-term rental cars, bicycles and scooters. The full scope of MOD is shown in Figure 15 from USDOT in 2016, broken down by what existed in 2016 on the left-hand side of the diagram, and the newer modes on the right.

Figure 15. Typology of Shared Mobility as Envisioned by USDOT in 2016

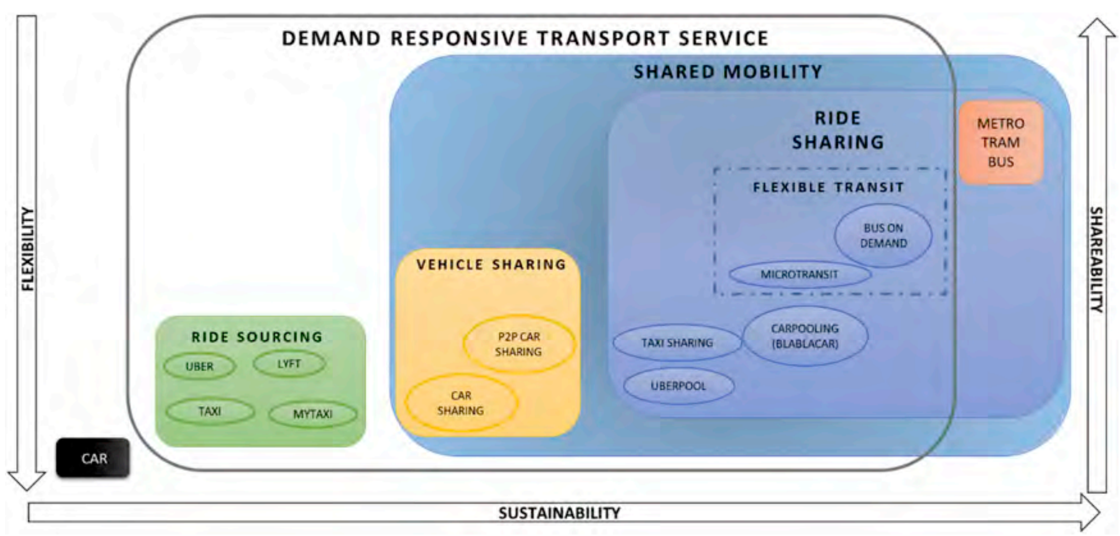
Source: Susan Shaheen, Adam Cohen, and Ismail Zohdy, "Report on Shared Mobility: Current Practices and Guiding Principles," USDOT, Federal Highway Administration, March 2016, https://ops.fhwa.dot.gov/publications/fhwahop16022/fhwahop16022.pdf

Because of our focus on public transit, the MOD of interest, shown in the right-hand circle of the diagram, is microtransit. Microtransit was defined by USDOT in 2018 as "a privately owned and operated shared transportation system that can have fixed routes and schedules, as well as flexible routes and on-demand scheduling. The vehicles generally include vans and buses."[39] In fact, a microtransit system can also be operated by a public transit agency with agency-owned vehicles and employee drivers, or under contract to a private firm. Furthermore, microtransit could also be a completely independent commercial vehicle fleet organization operated under contract to a private company to support movement of its employees, as is the case in the technology company employee commuter shuttles.

Before the pandemic there was strong growth in shared private transit offered by technology companies to their employees. For example, Google as of 2019 had contracted 300 buses to support commuting to work for 10,000 employees.[40] According to one source, as of early 2020 "there are an estimated 1,020 private commuter shuttle buses in the Bay Area, according to unpublished data from the San Francisco Bay Area Metropolitan Transportation Commission (MTC). Add that up and you have a private transportation system worth more than $250 million, the seventh largest transit system in the Bay Area, ahead of the ferry network, the County Connection buses, and the Marin Transit Network."[41]

Figure 16, from Inturri et al. in 2019, positions the demand responsive modes of transport against the highly flexible, dominant private car on the lower left, and makes some judgments worth considering on how flexibility declines and sustainability grows moving up and to the right of the diagram toward the fixed route modes of metro (heavy rail), tram (light rail and streetcar) and bus.[42] (Note however, the trend in the U.S. of growing adaptation of electric propulsion and automated driver assistance in private cars, which makes this mode more sustainable.) Within the "flexible transit" area of the diagram, the authors indicate that flexible, ride sharing, demand responsive transit can use vehicles large enough to be called buses, as well as the typical vans of microtransit.

Figure 16. Classification of Demand Responsive Transport Service Modes by Flexibility, Sustainability, and Shareability



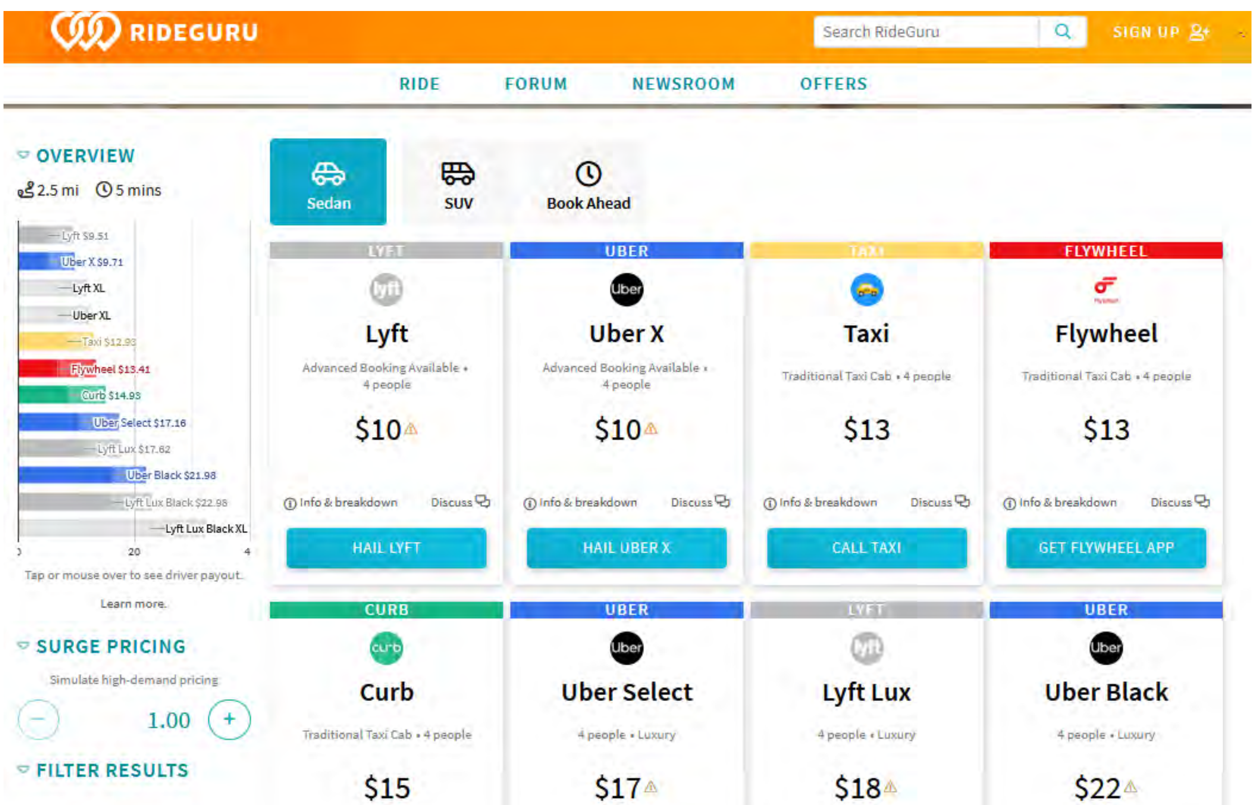
Source: Repurposed graphic in Inturri et al., "Multi-agent simulation for planning and designing new shared mobility services," 36, "Figure 1, Classification of Demand Responsive Transport services (own setup)," https://doi.org/10.1016/j.retrec.2018.11.009

According to one vendor, microtransit "is simply tech-enabled shared transportation that lives in the space between traditional fixed route transit and ride hailing technology. Its routes are nimble; its 'schedules' aren't really schedules at all, as they shift constantly based on rider demand; and its vehicles range in size from vans, shuttles, or buses."[43] As previously noted, microtransit can operate partially or completely along a route in an unscheduled fashion with flexibility to traverse it only when there is a customer who needs to be picked up or dropped off along the route. There can be flexibility as to where boardings and alightings occur; for example, a microtransit vehicle may serve the locations on a residential cul-de-sac street only at a designated stop where a through street is intersected.

Transportation Network Companies (TNCs) such as Uber and Lyft can also serve as providers of microtransit service under contractual arrangements with public transit agencies, providing subsidies that yield a set and affordable fare for the customer. Independently of public transit agencies and not under contract in most urban areas, private sector ride services such as taxicabs and new, smartphone-enabled TNC ride services such as Uber and Lyft provide rides between any two points, which can include train stations and bus transit centers, as well as final travel destinations. The public policy problem is that these services are priced to customers at a significantly over the subsidized services of public transit agencies, making them unaffordable for many individuals.

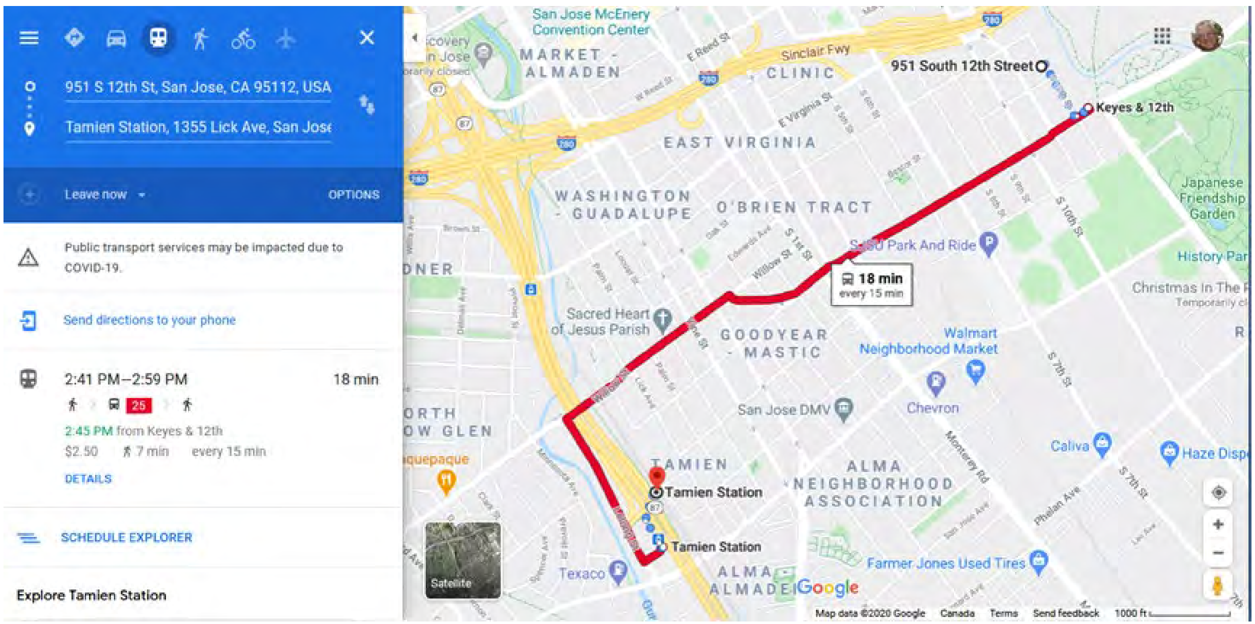
For example, the image in Figure 17 shows an example of pricing to travelers for a ride-hailed 2.5-mile trip in San José, California brought up as a request on the RideGuru app.

Figure 17. Example of Prices of Alternative Commercial Providers for a Short Commercial Ride in San José



The lowest price ride hail trip shown would use Lyft or UberX for a $10 fare, plus optional tip, and would take five minutes origin to destination once the car had arrived. A trip on a VTA public transit bus, as shown in Figure 18, would be 18 minutes including seven minutes of walking, and cost $2.50. The bus is scheduled to come every 15 minutes during the mid-afternoon time of day in the example. This is a typical comparison of ride hailing and fixed route transit; the former provides quicker travel but is more expensive than the latter.

Figure 18. Map of $10 to $15 Ride in a Street-Hail or E-Hail that Would be $2.50 on a VTA Bus



Source: Google Maps app

A series of research reports by Joseph Schwieterman and colleagues found a dozen cases as of 2018 where private sector ride providers, primarily Uber and Lyft, are contracted to supplement fixed route transit services, in some cases limited to supplementing access to transit stations and hubs.[44] Examples in California include transit agencies in Sacramento, Marin, and Vallejo subsidizing customer use of Lyft or Uber for trips to rail stations.

The growth of Uber and Lyft since 2014 has provided a competitive alternative to both private driving and transit patronage. However, it should be noted that UC Davis' work on Uber/Lyft adoption shows TNC use is an extension of private auto-mobility to a much greater degree than a substitute, and almost certainly decreases the use of public transit.[45]

In the particular case of serving low volume demand patterns typical of city suburbs, on-demand microtransit potentially offers higher levels of passenger miles per dollar than fixed route scheduled bus service, and likely offers higher quality service as well. For example, imagine a lightly used bus route that offers one bus per hour, and carries on average five people along the route in a 30-minute run. Those people may be served better by a six-person capacity that picks up the five passengers at five points close to their originations, and delivers them to five separate destinations in a computer-coordinated series of pickups and drop-offs.

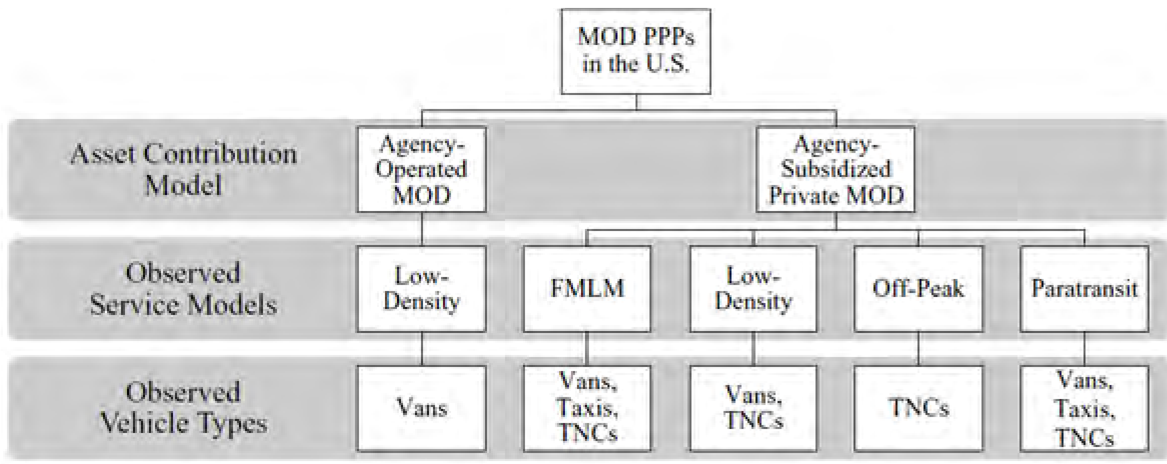
An important, typical application of microtransit is service that begins or ends at a train station, or bus transit center, and is called first and last mile (FMLM) service. However, FMLM is a narrow application of microtransit, and it can be mixed with other trip purposes. Many other combinations of rider types and trip purposes for small vehicle, on-demand transit, are more significant opportunities to address.

As pointed out by the Intelligent Transportation Society of America, mobility on demand can be achieved by various private or public service providers who deliver service independently from one another. Mobility as a service (MaaS) is a concept being developed in Europe that works to provide various mobility on demand options through a single shared smartphone app. The ubiquitous hand-held devices provide information on mobility options to help the traveler make a quick decision and order the ride from the preferred option. MaaS is a difficult, controversial concept and not considered further in this report. This research report focuses on arrangements set up by public transit agencies with particular in-house or contract vehicles.

7. Fragmentation of Transit Industry Response

We identified a useful framework for categorizing and analyzing ride service models that augment public transit. The framework comes from researchers at University of California Berkeley, who analyzed news clippings and websites to find examples of what they term Mobility on Demand Public Private Partnerships (MOD PPPs). From October 2017 to April 2018, Lucken et al. conducted 61 interviews with well-informed professionals from MOD companies, public transit agencies, transportation authorities, one regional planning agency, and three cities to gain insights on MOD PPPs.[46] The researchers displayed all of the MOD PPP options that were found to have emerged during the period 2016 to 2019 (Figure 19).

Figure 19. Varied Mobility On-Demand Contract Arrangements with Transit Agencies



Source: Repurposed from Lucken et al., 2019

The Berkeley researchers determined that most forms of MOD have been contracted to the private sector. Agency-operated MOD is generally dedicated to low-density service. All four observed service models in Figure 19—low-density, FMLM, off-peak and paratransit—are seen contracted out. In observed practice, these services are deployed with bounds on who is served that are set geographically, by time of day and day of week, and by eligibility characteristics as shown in Table 6. Ride services are offered in different categories of location and time-of-day. These bounds are set to avoid the new MOD options attracting customers away from the traditional fixed route transit that is the agency mainstay.

Table 6. Classification of Transit Agencies' Market Targeting of Subsidized Microtransit

	Geo-Spatial **Only serve trips that:**	**Temporal** **Only serve trips made during:**	**Socio-Demographic** *(e.g., Income, Ability, Age, Frequency of Transit Use)* **Only serve trips made by:**
First-Mile/ Last-Mile	Start/End at Fixed-Route Public Transit Stop or Station	Public Transit Service Hours (or Peak Hours)	Anyone, But Could Restrict Eligibility *(e.g., only serve commuters or those who own transit station parking passes)*
Low-Density (Geo-Spatial Gap-Filling or Replacement)	Start/End Outside Fixed-Route Service Area *(e.g., within buffer zone of replaced bus route)*	Public Transit Service Hours	Anyone, But Could Restrict Eligibility
Off-Peak (Temporal Gap-Filling or Replacement)	Are Within Public Transit Service Area	Off-Peak Hours *(e.g., night, possibly midday)*	Anyone, But Could Restrict Eligibility *(e.g., only serve low-income night-shift workers)*
Paratransit	Are Within Public Transit Service Area	Public Transit Service Hours	Persons with Disabilities; Senior Citizens

Source: Lucken et al., 2019

A potential transit agency goal is to use microtransit to provide additional capacity to serve customer markets which are not adequately served by existing fixed route transit. At the same time, the characteristics of MOD PPP and its service patterns could potentially be adjusted to yield better service than provided already to those riding on fixed route transit. This report takes up that question in Section 13, On-Demand Microtransit Serving All Customers.

8. The VTA FLEX Microtransit Service

VTA was the Bay Area's pioneering public transit agency in its offering of an agency-operated, smartphone app-based, on-demand microtransit ride services, arguably innovative in the context of the entire U.S. VTA sought to be an industry leader in developing new solutions for transportation problems, and in fact this effort was a valuable contribution to understanding what microtransit can be, and the requirements for it work, which influence the direction of this report.

As described by VTA staff in a report to the Board of Directors, FLEX was a six month pilot project testing on-demand transit service in an initially defined 3.25 square mile zone of high unmet customer demand in North San José.[47] The program was later expanded to 5.5 square miles and became more oriented to a first and last mile concept by including a light rail stop (see map in Figure 21). Registered customers used a downloaded smart phone app to request rides and to travel within the zone, or they could call a staffed service center on the telephone that would put the request into the computer system and the software determined the appropriate vehicles to dispatch. Several hundred FLEX access points were marked with a sidewalk decal to make points of access more controlled and certain for both customers and drivers. The app provided status updates to the customer on the arrival timing of the bus.

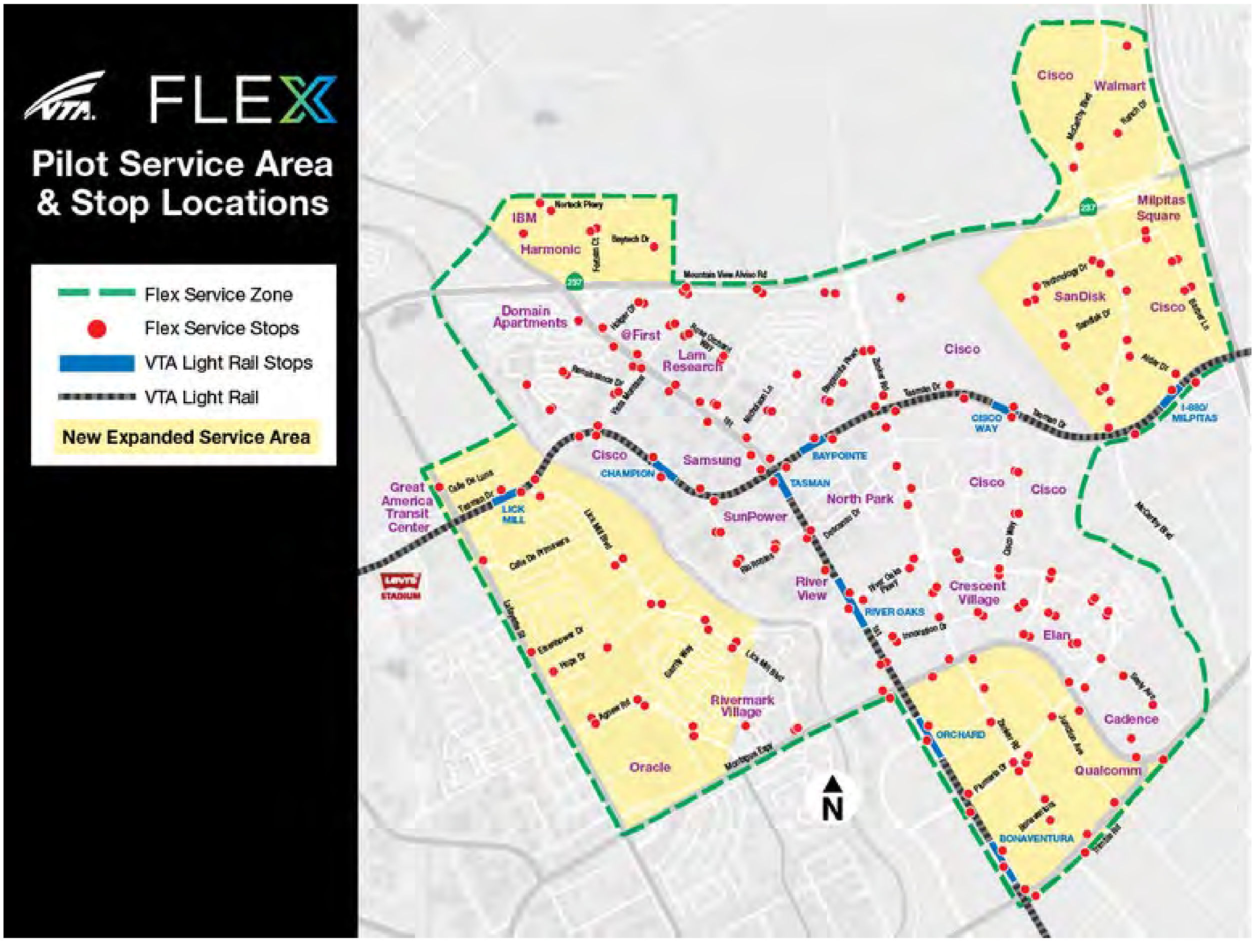
Figure 20. VTA FLEX Microtransit Vehicle in 2016

Source: VTA, https://www.flickr.com/photos/vtaphoto/24354950836/in/album-72157663554383905/

The service operated on weekdays from 5:30 AM to 8:30 PM, with four 26-passenger shuttle buses that were readily available in the VTA fleet inventory, shown in Figure 20. However, they were too big for rapid maneuvering on dynamic routings and for the small passenger loads achieved. The size might have been appropriate for the social distancing requirements of the 2020 pandemic. On the positive side, these vehicles would accommodate wheel chairs, fully meeting the ADA standard for transit vehicles. The FLEX service was meant from the beginning to provide shared rides, meaning multiple customers might board and depart during any one ride for a particular customer. The average wait time for a requested ride was approximately 7.5 minutes (including time walking to the stop), and the average time on the vehicle was a little over eight minutes.

The demand response dispatching algorithm assigned incoming trip requests to vehicles in real-time "reasonably well," but the software was unable to handle pre-scheduled trip requests mixed in with real-time, short-notice, on-demand requests, so the service operated without this typical feature. VTA surveys found that 70% of customers desired this capability, an equivalent example being the typical consumer interest in ordering a morning taxi ride the evening before. This missing function was one issue that limited customer attraction to FLEX, but more importantly, timely response to requests was limited by failures of the trip assignment algorithm that would sometimes assign a new trip to a vehicle several miles away from the pick-up when another empty vehicle was waiting in the immediate vicinity. Another reported flaw was that the software algorithm ensured customers' ride time would not exceed 20 minutes but did not include vehicle load factor in its optimization, and the overly large buses rode lightly loaded.

Figure 21. Pick-Up and Drop-Off Points for 2016 VTA FLEX Microtransit Service



Source: VTA, https://web.archive.org/web/20170419190127/https://www.vta.org/getting-around/vta-flex

Once assigned to a bus, the driver received directions on a tablet computer, which worked well. The FLEX service area also had numerous cell service dead zones. All the software technical issues from 2016 have been resolved in improved 2021 microtransit service offerings around the world, using more up-to-date and capable scheduling and fleet management software applications.

Another problem area was fare payment. A single ride fare was two dollars after 9:30 AM and before 3:30 PM, and three dollars during the morning and evening peak commute hours. But as stated on the FAQ for FLEX, "FLEX does not accept Clipper cards, VTA Monthly Passes, VTA Day Passes, VTA Express Day Passes, Cash, Eco Pass nor any other VTA forms of fare."[48] VTA wanted to integrate FLEX fare payment with the Bay Area Clipper smart card system, but they could not. This payment mode would have required FLEX to install fare-box readers on the four shuttle buses, which was not possible because of other regional fare collection modernization underway. Instead, with no fare boxes or devices on the bus, the service required all customers to enter a credit or debit card to an online user account prior to riding the first time as part of initial registration. Unbanked customers best option was a general purpose prepaid debit card bought with cash at a retail store.

The FLEX service was not used by travelers in numbers sufficient to justify the operational costs. The ridership across the four vehicles was 16 per day during the first three months and 33 per day in the closing six months after zone expansion and some promotional activity. Just 2,714 trips were taken on FLEX over the course of its six months of life.

Operating cost averaged $200 per passenger, with 0.4 boardings per revenue hour and a fare-box recovery of 1%, compared to VTA's overall performance of 15 boardings per service hour and fare-box recovery at 12.3% in this 2016 period. On feedback surveys, passengers said they would have been willing to pay a few dollars more, but that would not have been enough to raise the fare-box recovery rate to a more acceptable rate of 12% or higher.

FLEX was funded by a $1.13 million Metropolitan Transportation Commission (MTC) Transportation Demand Management grant. Dividing the 2,714 trips by the total grant, yields a cost of $416 per rider, which is double the VTA normal bus operating cost and a reflection that extraordinary one-time planning and support effort were required to put FLEX on the road.[49]

Of the 2,677 registered rider accounts created, only 313 actually used the service, and 42 customers used FLEX 20 times or more in six months. Twenty people used the service multiple days per week.

On the cost side, the use of regular VTA drivers working shifts according to the terms of a union contract, plus the requirements of the bidding/assignment protocols, reportedly led to some overstaffing compared to usual operator requirements. Staff and board committee reviews in the public record suggested that private sector engagement in operations could reduce cost and increase flexibility in balancing workload with staff availability. However, VTA staff noted more recently to the Ride & Ride research team that these comments do not *prove* that private sector engagement would actually reduce cost and increase flexibility in work assignments.[50]

On the demand side, VTA staff now understand that much more marketing activity would be needed to ramp up citizen demand for this kind of VTA service. Survey evidence demonstrated, that from the customer point of view, considering the fare juxtaposed with the value of the service the FLEX service was a cost-effective alternative to TNC service from Uber and Lyft.[51]

9. VTA Continued Action on Microtransit

After three years of no visible microtransit services following the shutdown of FLEX, in 2019, VTA began funding city governments in its service territory, with State of California funds, for innovative MOD services that supplemented, but did not compete with, VTA fixed route services. The first grant award was to City of Cupertino to establish a general purpose on-demand van service for point-to-point trips within the city limits, even though four VTA bus routes operate there. The City awarded a sole source contract to Via, and began service with six vans in October 2019.[52] The service enjoyed steady growth through the beginning of the pandemic, but experienced a fall in ridership starting in late March, and the service was suspended in August 2020.

Aiko Cuenco, a veteran transportation planner at VTA, prepared a memo on August 21, 2020 for the VTA Capital Program Committee which described the agency's internal thinking on providing transit to low-density suburban areas.[53] She noted that "Providing transit to low-density suburban areas is one of the toughest environments for transit to serve successfully. In such cases, alternative transportation option could be more compatible and cost effective in meeting the existing demand for transit." VTA has long been interested in exploring alternative service models and mobility options, in a program called Core Connectivity, and she reviewed work going back to 2015, when a toolkit of shared mobility strategies was developed. That toolkit was revealed in a 2018 presentation to the board; it amounts to a series of service configurations.

Cuenco contrasted existing traditional mobility strategies found in California with newer emerging mobility strategies like public–private partnerships that engaged TNCs and private microtransit vendors in the delivery of public transit services.

Earlier research findings of VTA presented in a 2018 Advisory Committee update were that:

- Public-operated on-demand transit can increase coverage but is not yet cost effective
- Flexible transit service models have low productivity
- Emerging mobility services are still rapidly evolving, making it difficult for public agencies to know where the real opportunities lie for their agencies and context.[54]

VTA by that time had reviewed more than 20 pilot microtransit programs, including their own FLEX, and found their performance to be characterized by high cost and low utilization. The best reported case carried 3.3 passenger trips per vehicle revenue hour at a cost of $17.65 per trip, compared to $9.40 per trip on a fixed route bus being replaced. AC Transit's microtransit in Castro Valley performed at an average of five trips per hour and a cost of $63.57 per trip.

Nevertheless, there was a VTA interest expressed in the January 2018 Core Connectivity Update to "focus on leveraging funding and partnership opportunities to deliver cost-effective alternative mobility solutions."[55]

Three areas of development for VTA microtransit pilots were described in the August 21, 2020 memo, summarizing as follows:

- Partnering with a private on-demand service provider to offer paratransit customers the option to travel on shorter notice than is now available.
- Partnering with the City of Morgan Hill for point-to-point mobility services, with special attention to first and last mile connection to the Caltrain station.
- Support for first and last mile on-demand flexible shuttle between the new employment district of Peery Park and the Sunnyvale Caltrain station. This one is still pending as of early 2021 with implementation slowed by the pandemic.

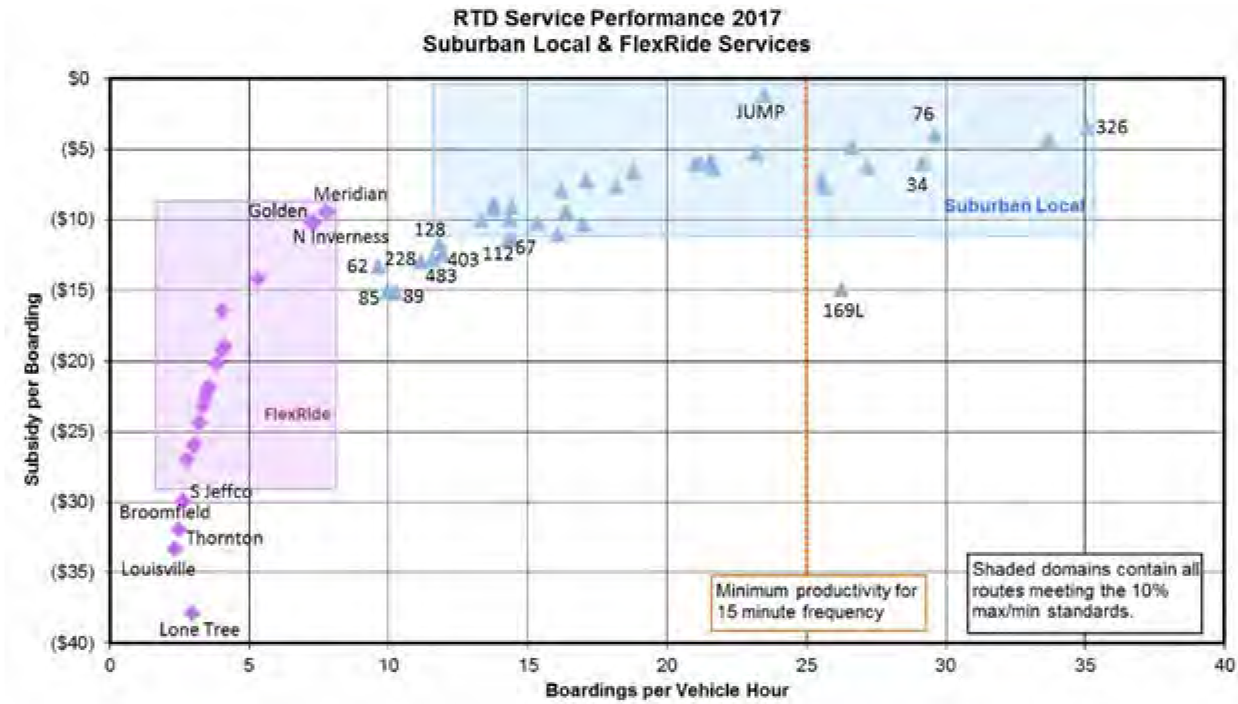
The next section considers data on the microtransit potential from outside of VTA.

10. Analyzing the National Transit Database for Insight

Since 2018, the private sector nationwide has advanced in designing, developing, and implementing alternative transit service configurations that are potentially cost-competitive with lower volume fixed route services for the same ridership level. Thus, for some low-demand neighborhoods, walking to a bus stop to board a scheduled bus could be replaced by walking to a much closer pickup point to meet a multi-passenger van or minibus that had been summoned by the customer five to twenty minutes earlier. Furthermore, if the customer wants a fixed time experience for every day or certain days, current technology supports offering that preference as well.[56]

Denver Regional Transportation District illustrates the tradeoff between subsidized cost per boarding and boardings per vehicle hour (Figure 22). Cost is expressed as a negative number and gets larger in absolute value moving downward on the graph. Subsidy decreases as boardings per hour rise. The blue triangles are fixed route buses, while the violet diamonds are an on-demand microtransit service called Flexride which follows routes rather than being dispatched point-to-point.[57] The sweet spot for microtransit in this agency appears to be between five and ten boardings per vehicle hour, where the subsidy for fixed route trends higher as boardings drop. However, pushing on-demand microtransit past six boardings per hour and toward ten is difficult in most environments.

Figure 22. Denver Region Microtransit Productivity Trades Off Against Cost



Note: Blue colored points represent fixed route, and violet colored points represent rides dispatched point-to-point.
Source: Denver Regional Transportation District

A survey of all U.S. transit agencies in the first quarter of 2018 found that 13 agencies had deployed demand responsive microtransit and they reported ridership per vehicle hour in the range of 2.4 to 4.7 passengers per revenue hour.[58] The Transportation Research Board report describing this survey notes that higher numbers than this have been seen in Denver and elsewhere coming from "feeder services rather than circulator services… [that generate] higher ridership per hour due to a greater number of spontaneous boarding at stops that generate or attract larger numbers of riders such as rail stations, transit centers, schools, or employment centers." A USDOT report from 1981, found in a review of five field reports from the 1970s, that 14 dial-a-ride paratransit services of that era reached an average of 9.6 customers per vehicle hour.[59]

The Ride & Ride research team examined what the USDOT's NTD revealed for the performance of California transit agencies in 2019, the last full pre-COVID year. We examined the modes that were most pertinent to the consideration of on-demand microtransit. Our interest lay in determining whether microtransit performed financially comparable to fixed route bus service.

Table 7 shows data for all transit agencies in California that operate buses, on-demand modes, or van pools. The two on-demand modes measured in the NTD in 2019 were paratransit, mostly for ADA eligible customers, and demand taxi, which means taxicabs or taxi-like services such as Uber and Lyft serving customers in a formal arrangement set up by the transit agency. Commuter bus service (CB) and Bus Rapid Transit (RB) were excluded.

Table 8 shows how the performance numbers for existing transit service in California suggests that a portion of fixed-route traditional transit could feasibly operate as on-demand. In these calculations, we are in effect treating all transit agencies in California as one giant agency. We consider, as a thought experiment, the idea of moving the least productive one hundred million fixed route bus miles in a year over to microtransit. We assumed a rate of 15 boardings per vehicle hour or less for these fixed route services. We then determined under what assumptions these passengers can be transported aboard eight passenger vans for the same operating cost.

The top row of Table 8 shows a baseline case for buses that operate at an average of 15 boardings per revenue service vehicle hour, the minimum target performance typically sought for such service case at VTA. Cost calculations validated in Table 7 using reported data indicated that using the total 2019 fixed route bus services averages (15 boardings per vehicle service hour, 11 miles per hour per vehicle service mile per vehicle service hour, with a trip length averaging four miles and the typical operating cost of $13 per vehicle revenue mile), it would require a total operating budget of $953.3 million dollars to serve 100 million passengers in a year. This would account for approximately 13% of the boardings on local buses in 2019.

Three complete microtransit substitutions for these fixed route services are given on the next three lines of Table 8, showing the effect of using smaller vehicles that pick up a lower number of passengers on-demand. We assumed an expansion of the average trip length from four miles to six in order to allow for rider interest in going further on a new service. We simulated boarding rates of 2 and 3 per hour, both easily achievable, in microtransit alternatives #1 and #2 respectively. Then we lowered the vehicle operating cost to six dollars per mile, more in line with what is achieved in the existing on-demand services listed in Table 7. The result in each case yields a modeled total operating cost that is three to four times that of the fixed route service. This high cost of microtransit compared to fixed route buses is what pushed VTA away from microtransit following their FLEX pilot in 2016.

In order to reach the lower cost level of existing fixed route services requires expanding the passenger pick up rate to 4.5 per hour and cutting the operating cost further to three dollars per mile, still considerably higher than the current IRS standard deduction of 57.5 cents per mile for a private passenger vehicle, but which does not include compensating the driver. These are the parameters of microtransit alternative #3.

At this higher customer rate of 4.5 boardings per hour, the required vehicle hours drop down and with the lower cost of vehicle hours, the cost per boarding drops from $28 in alternative #2 to $9 in alternative #3, making this last alternative more efficient than the fixed route bus benchmark at $10 per boarding.

The microtransit alternative #3 vehicle operating cost of $42 per hour compared to the agency average of $143 per hour for fixed route buses is an aggressive target given the average wages that transit agencies pay their drivers. VTA, for example, pays drivers $36.63 per hour.[60] However, with sufficient density in the microtransit service zones, sophisticated ride request and dispatching technology supporting multiple riders going in the same direction, and with eventual transition to robotically operated vehicles, the hypothesized microtransit alternative #3 is an achievable target.

These calculations certainly underline the challenge of making microtransit as affordable as fixed route service. As VTA analyst Adam Burger notes, "There are reasons to be skeptical of this concept."[61] The Ride & Ride research team examined what might be possible in the case of some VTA examples, described next.

Table 7. 2019 Performance Data on all California Transit Agencies from National Transit Database

	Boardings in 2019 (000)	Average trip length (miles)	Passenger miles (millions)	Boardings/ revenue hour	Vehicle MPH during revenue hours	Operating cost per revenue mile	Operating costs (millions)	Vehicle hours (000)	Vehicle miles (millions)	PM/ VM
Motor Bus (MB) Mode; Total for 139 agencies	776,820		2,982				$4,266	28,258	318.9	9.4
MB: Average per agency	5,589	3.9	35.9	27.5	11.3	$13.38	$30.7	203.3	2.3	15.7
Demand Response (DR) Mode: Total for 124 agencies	12,059		106.3				$515.9	6,014.7	84.9	1.3
DR: Average per agency	97.2	9.8	1.6	2.0	14.1	$6.08	$4.2	48.5	0.684	2.3
Demand Taxi (DT) Mode: Total for 24 agencies	3,476		38.5				$109.8	1,115.5	24.2	1.6
DT: Average per agency	144.8	12.2	2.6	3.1	21.7	$4.54	$4.6	46.5	0.992	2.6
Van Pool (VP) Mode: Total for 12 agencies	10,964		441.8				$48.7	1,976	75.6	5.8
VP: Average per agency	913.7	40.4	36.8	5.5	38.2	$0.64	$4.1	164.7	6.3	5.8

Source: National Transit Database 2019 summary

Table 8. Modeling of Microtransit Scenarios based on Performance of Existing California Transit Agencies (part one)

Compared service models	Model Input: Boardings/ revenue hour (Assumption)	Model Input: Vehicle MPH during revenue hours (from MB above)	Model Input: Operating cost per revenue mile (Assumption)	Calculated costs from the model inputs (millions)	Vehicle Hours (000)	Revenue vehicle miles (VM) (millions)	PM/VM	Calculated cost per vehicle hour	Calculated cost per boarding
Fixed Route Bus as usual	15	11	$ 13.00	$953	6,667	73.3	5.5	$143	$10
Microtransit alternative #1	2	14	$ 6.00	$4,200	50,000	700	0.9	$84	$42
Microtransit alternative #2	3	14	$ 6.00	$2,800	33,333	467	1.3	$84	$28
Microtransit alternative #3	4.5	14	$ 3.00	$933	22,222	311	1.9	$42	$9

Source: National Transit Database and Ride & Ride research team assumptions

Table 9. Modeling of Microtransit Scenarios based on Performance of Existing California Transit Agencies (part two)

Compared service models	Test Case Annual Boardings (000)	Average Trip Length (miles)	Passenger Miles (PM) (000)
Fixed Route Bus as usual	100,000	4	400,000
All Microtransit alternatives	100,000	6	600,000

Source: National Transit Database and Ride & Ride research team assumptions

11. Potential VTA Fixed Route Transformation to On-Demand

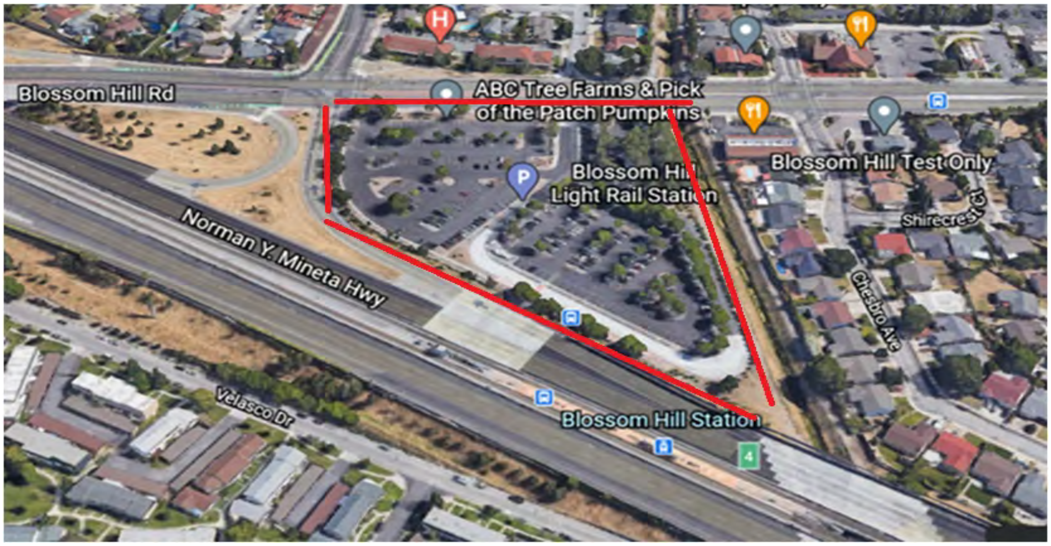
With VTA data provided by agency staff and documents, the Ride & Ride research team arranged with private microtransit vendor Via for computer based simulations of on-demand service for two neighborhoods currently served by VTA with fixed route service. Via came to the attention of this projects' researchers through its visible participation in a microtransit study with the consulting firm Boston Consulting Group.[62] Via was also singled out by the vendor selection process in the City of Cupertino for the pilot project described previously, with Via named as the "sole source provider of a community shuttle program" as of June 2019.[63]

We stress that the selection and performance of simulations in this section do not reflect any plans or decisions by VTA staff, and represents an independent exploration of potential opportunities.

Vicinity of Blossom Hill Station

Via and other vendors evaluate on demand service alternatives by ridership demand, number of vehicles, capacity of vehicles, waiting time, number of pickup points per block face, fare level, and a cost per rider target. One area examined by the Ride & Ride research team was the corridor in Southeast San José served by the eastern half of the VTA bus route number 27, serving the Blossom Hill light rail station (Figure 23) and other points along Blossom Hill Avenue. This station attracted the team's attention because it has been designated as a VTA development target for housing on VTA property currently existing as an underutilized park and ride lot. A proposal from a housing developer was received by VTA in 2020 (Figure 24) and is being considered as of this writing.

Figure 23. Satellite View of the VTA Blossom Hill Light Rail Station (outlined in red) and the Surrounding Area



Source: Google Earth

Figure 24. Housing Proposed for a Portion of the Park-And-Ride Lot at VTA Blossom Hill Light Rail Station


SAN JOSE spotlight

Proposed housing project at San Jose's Blossom Hill station would help fund transit

by Sonya Herrera

SEPTEMBER 16, 2020

The Santa Clara Valley Transportation Authority (VTA) is looking to build 328 apartments at the Blossom Hill light rail station in south San Jose, with revenue from the development to be used to fund transit operations.

Source: Clipping from the *San José Spotlight,* September 16, 2020, https://sanjosespotlight.com/proposed-housing-project-at-san-joses-blossom-hill-station-would-help-fund-transit/

According to the NTD, VTA buses operate at a cost of $190 per vehicle revenue hour. Route 27 runs every 30 minutes, therefore, cutting the route in half to just the part shown in Figure 25 would eliminate 33 hours of service per weekday. The maximum passenger loads pre-pandemic in February was 7 riders, at peak load point. Based on VTA ridership data, weekday boardings for this half of the route are approximately 500 per day. Thirty-three hours multiplied by $190 equals

$6,270 per day, or $1.9 million per year using a standard transit weekday-to-all-days annualizing factor of 305.

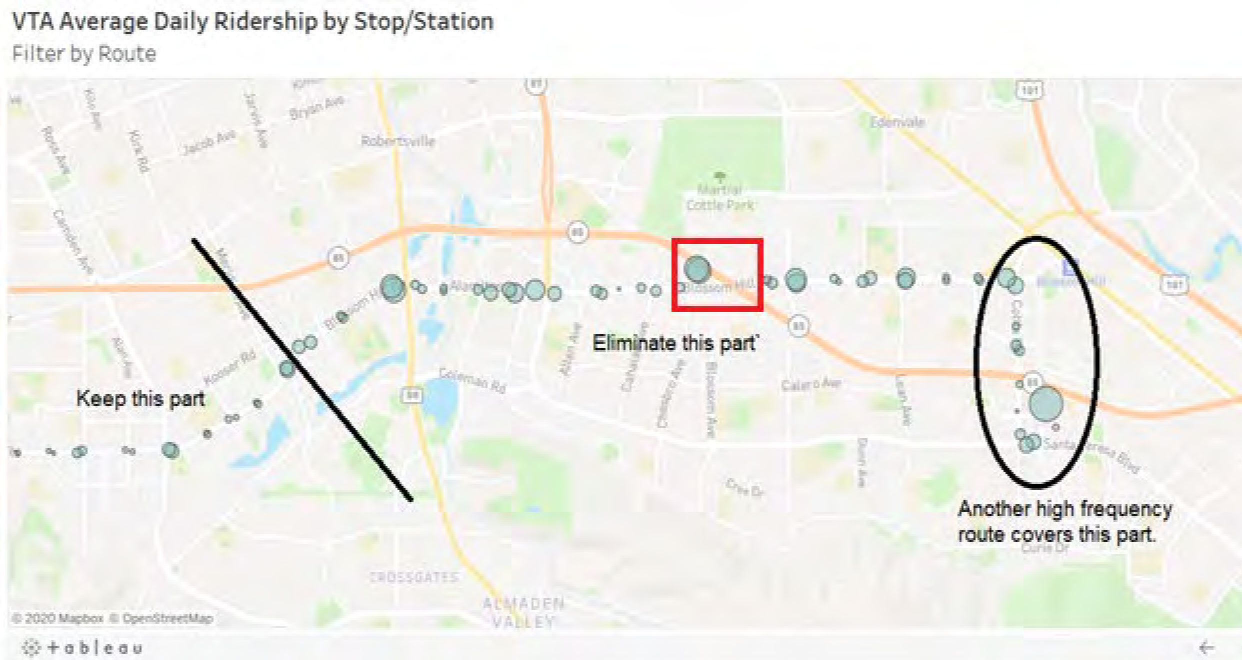
Simulations by Via suggest that a portion of route 27 could reasonably be transformed into an improved on-demand transit service with 10 eight-passenger vans that served all neighborhood homes and businesses on both sides of the route, plus two light rail stations, as shown in Figure 25.

Upgrading the eastern half of the Route 27 local bus (map shown in Figure 26) running every 30 minutes, into an on-demand service in the zone covering the route and 20 minutes walking distance to the route, as shown in Figures 27 and 28 could potentially make the $1.9 million spent annually on that route more productive by offering a higher quality of service.

Via claims to deliver service at $12.50 per boarding which can be compared to the modeled microtransit alternative #3 in the previous section, which showed $9 per boarding as its cost efficiency. Via claims it could provide 500 trips per day at this cost per boarding, with up to 10 vehicles in peak and fewer off-peak. Waiting time emerges from the simulation as six to seven minutes following a request for a ride. Five hundred trips on weekdays multiplied by the 305 annualizing factor and by $12.50 results in the same $1.9 million annually as the fixed-route bus number 27

However, VTA staff noted that, "Boardings that occur on a segment of Route 27 were conflated with point-to-point trips within an area that the route travels through. Eliminating the segment of that route will depress boardings on other parts of the route and worsen mobility for longer distance trips that currently use transit; …to just replace a segment of a route and using boardings alone rather than consideration of trip distances/passenger miles traveled gives only a partial sense of the change in overall service utility."[64] As such, a more nuanced investigation would be required before deciding to deploy the type of service explored here in a preliminary way.

Figure 25. Eastern Half of VTA Route 27, Potentially Converted to On-Demand Service, between the Line Illustrating the Boundary with the Western Half, and the Area Inside the Oval which would be Eliminated for Route 27 and Still Served by Frequent Service Route 68



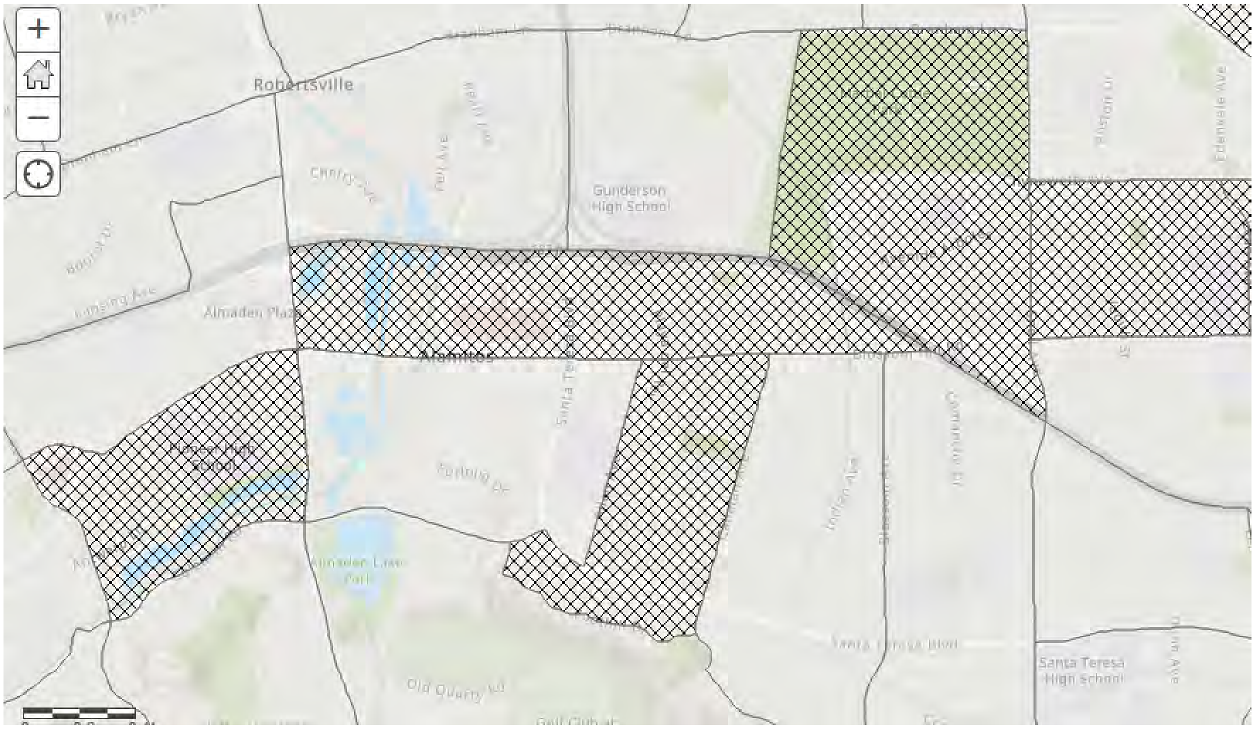
Note: The Blossom Hill light rail station is at the large dot inside the red square. A different Caltrain commuter rail stations named "Blossom Hill" is inside the oval.
Source: Janice Soriano, "VTA Average Daily Ridership by Stop/Station,"
https://public.tableau.com/profile/janice.soriano#!/vizhome/SystemwideRidershipbyStop/Dashboard1

Figure 26. Portion of VTA Network Map Showing Eastern Portion of Bus Route 27

Note: High frequency bus routes shown in red. Light rail is the thick blue line. Thin blue lines, including route 27, are community service routes with headways of 30 minutes.
Source: Excerpt from VTA network map, https://www.vta.org/sites/default/files/2021-02/VTA_MainMap_020821.pdf

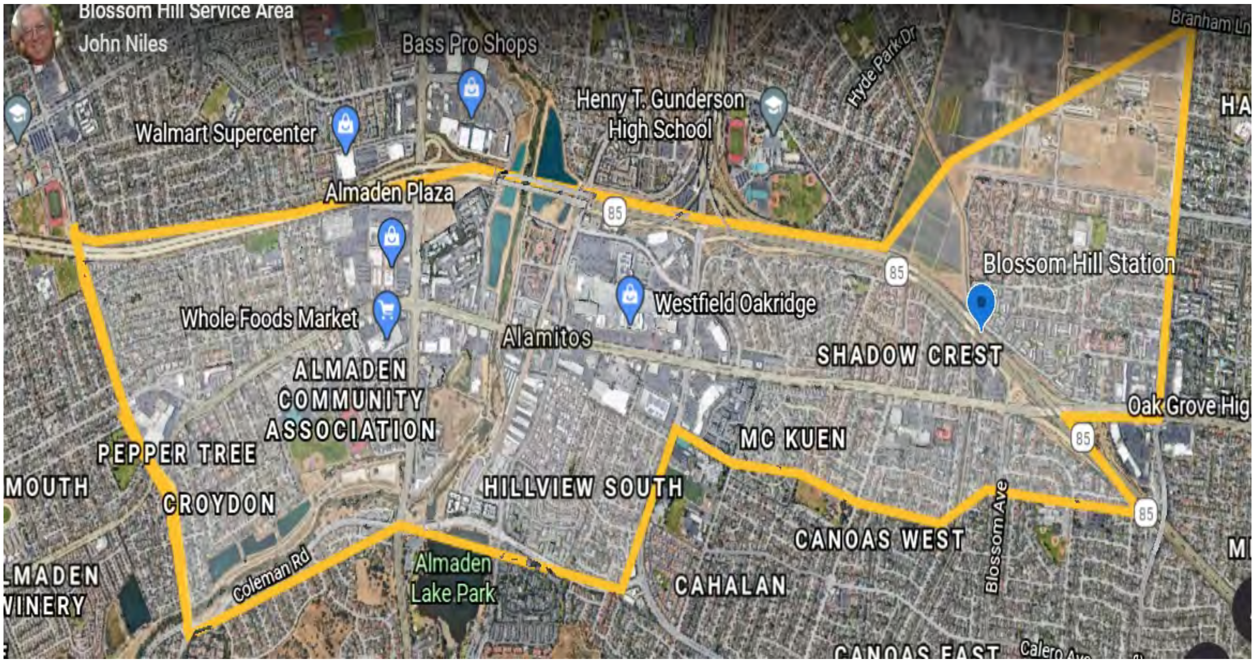
By design, as a reason for selection, this proposed territory for on-demand point-to-point service covers some low income neighborhoods identified by the City of San José as shown in the Figure 27 map and in the satellite view in Figure 28.

Figure 27. San José Census Tracts with High Proportion of Low-Income Households



Source: City of San Jose map, https://www.arcgis.com/home/webmap/viewer.html?url=https://services2.arcgis.com/RiZWfy7B1r76pKTz/ArcGIS/rest/services/low_income_census_tract_poverty_zone/FeatureServer/0

Figure 28. Proposed Service Area of VTA Territory Modeled for an On-Demand Microtransit Service



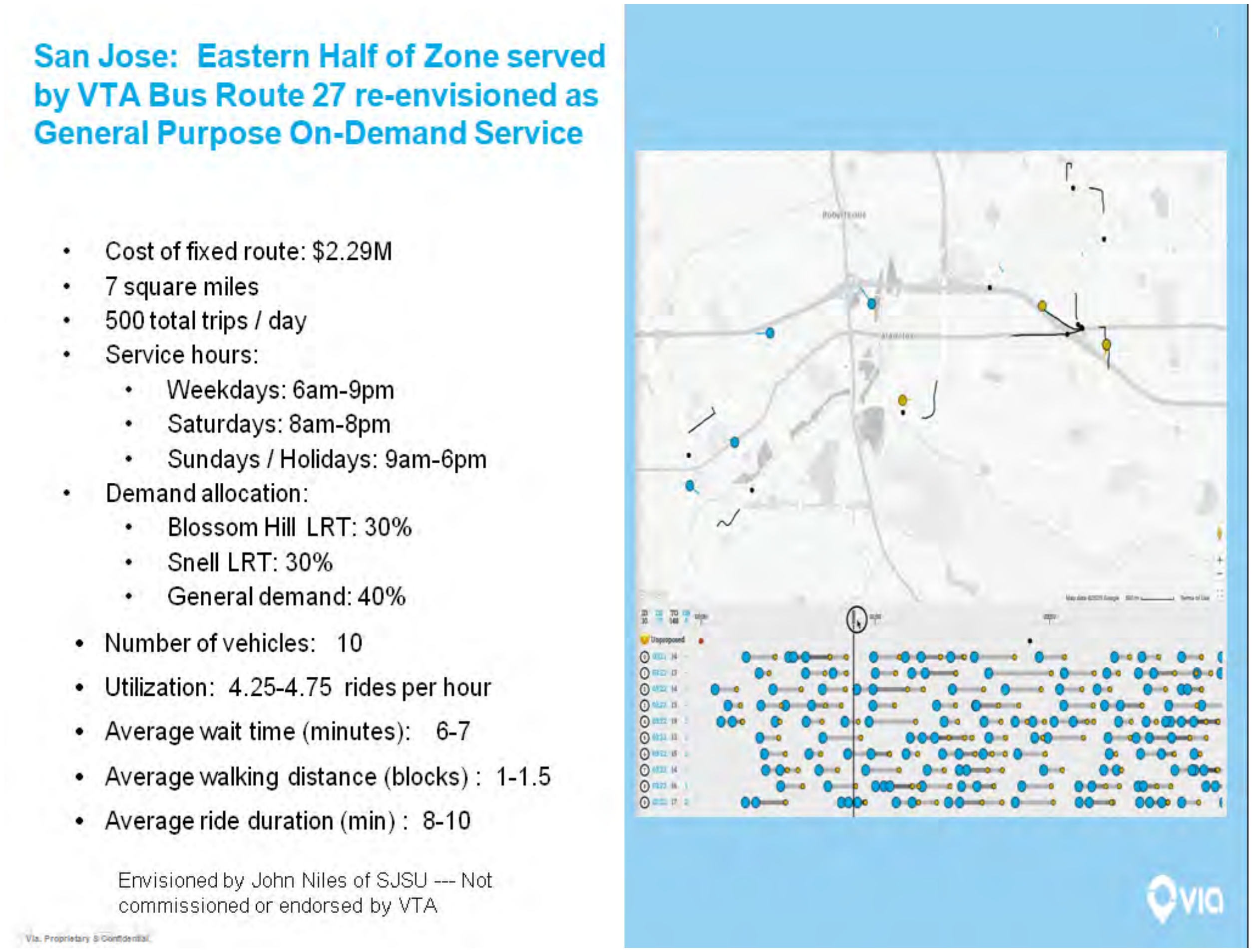
Note: Service zone outlined in orange is drawn for research purposes by the Ride & Ride research team as an area for modeling of on-demand service.
Source: Google Earth.

A screen print of the microtransit simulation results provided at the request of the Ride & Ride research team as a preliminary investigation of potential is shown in Figure 29.

A hot link to an animation of the simulation provided by private microtransit service vendor Via is:
https://www.dropbox.com/s/i9z3xlkz7tj6zoj/VTAroute27-OnDemandTransform.ppsx?dl=0.

To see the simulation operate, download the file linked here and run as a presentation in PowerPoint. The Ride & Ride research team emphasizes that the simulated configuration is not a plan or proposal either from the VTA transit agency or to the agency, but rather an independent examination and illustration of potential gains in efficiency and geographic coverage.

Figure 29. Simulation of Blossom Hill Hypothetical Microtransit Zone



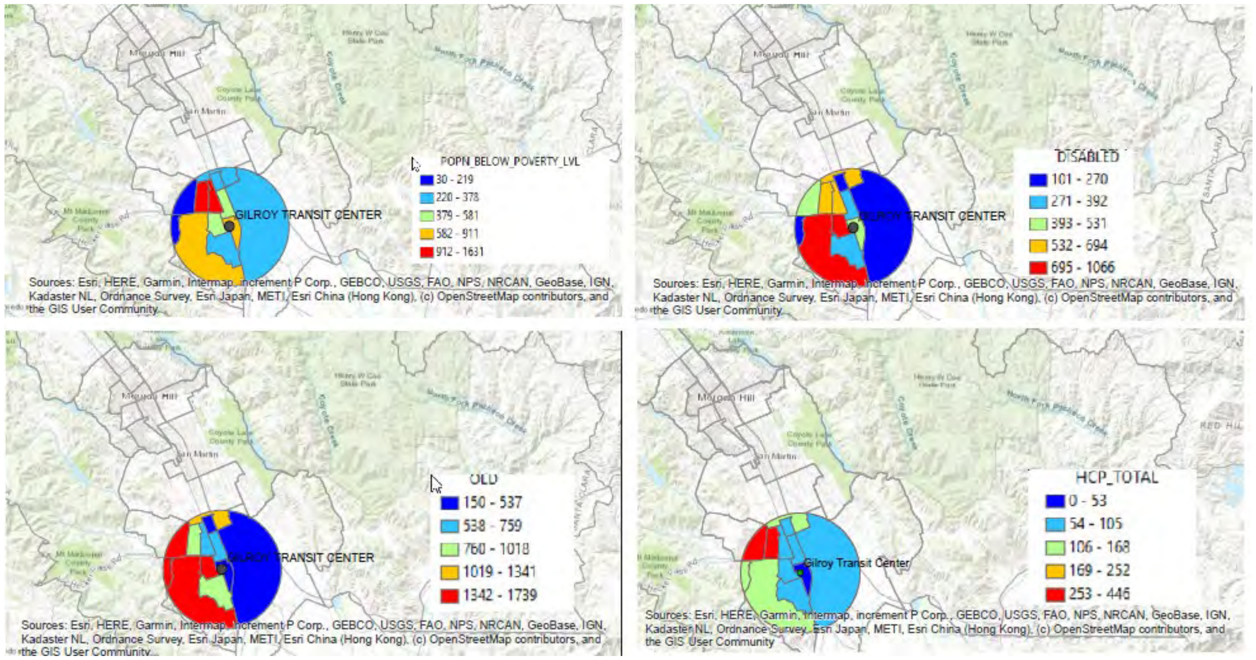
Source: Specifications provided by the Ride & Ride research team

City of Gilroy

As a second location, an additional site centered on the Gilroy Transit Center was included based on a comment from a VTA staff member who made the Ride & Ride research team aware of the relatively high number of elderly and low income transit riders in the City of Gilroy (Figure 30) who might appreciate a non-private-automobile mode of access to the transit center, which provides both bus and rail access to center city San José, for example, VTA Route 68 operating all-day 15 minute service to downtown.

The City of Gilroy in the southern part of Santa Clara County is a part of VTA territory where we examined the feasibility of converting three existing fixed bus routes, scheduled for 30 minute frequency, to on-demand service operating for the same cost but providing more convenient travel options to more destinations in the Gilroy community.

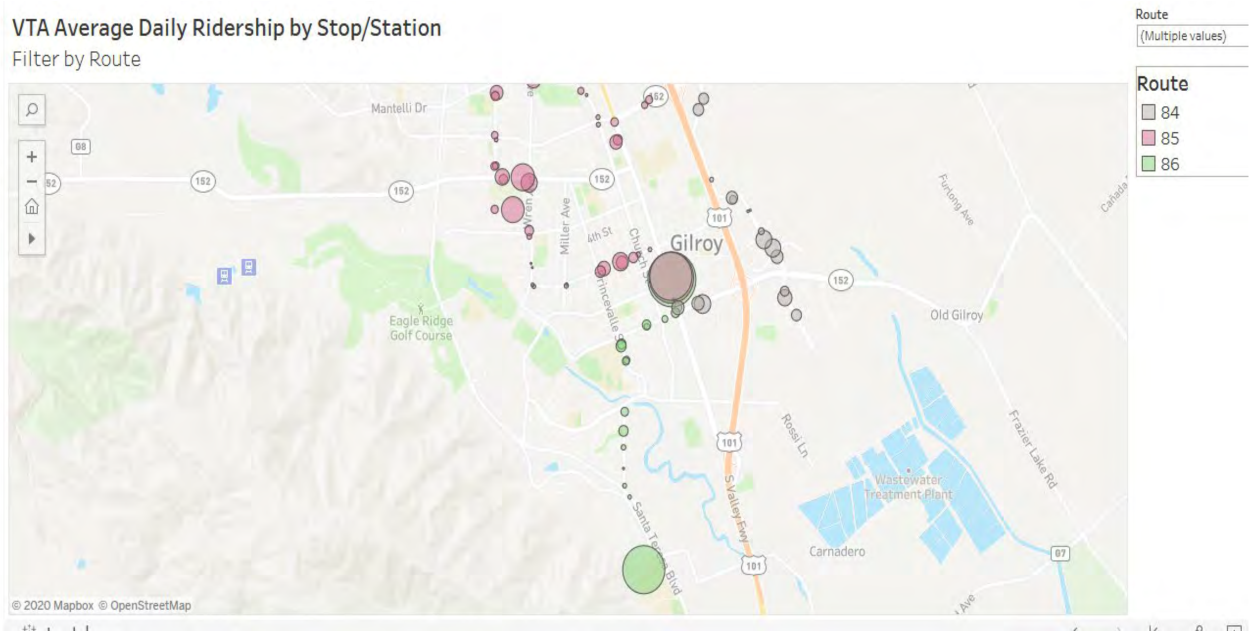
Figure 30. Transit Relevant Characteristics of Resident Close to Gilroy Transit Center



Note: Census data indicates in red coloring that in a three-mile radius around the transit center, there is a notable population of seniors and disabled on the west side of Gilroy, and the number of low-income households is substantial as well. HCP is health care professionals, a category of essential worker. Red indicates high values, blue indicates low values.
Source: U.S. Census, American Community Survey

In Figure 31, the ridership map for Gilroy, the two biggest circles are under 100 boardings per weekday, counted in February 2020, pre-pandemic. The uppermost big purple circle is the transit center where a VTA express bus to downtown San José departs every 20 minutes, plus two round trips per day on Caltrain. The lower big green circle marks the site of Gavilan College.

Figure 31. Ridership at VTA Bus Stops in Gilroy



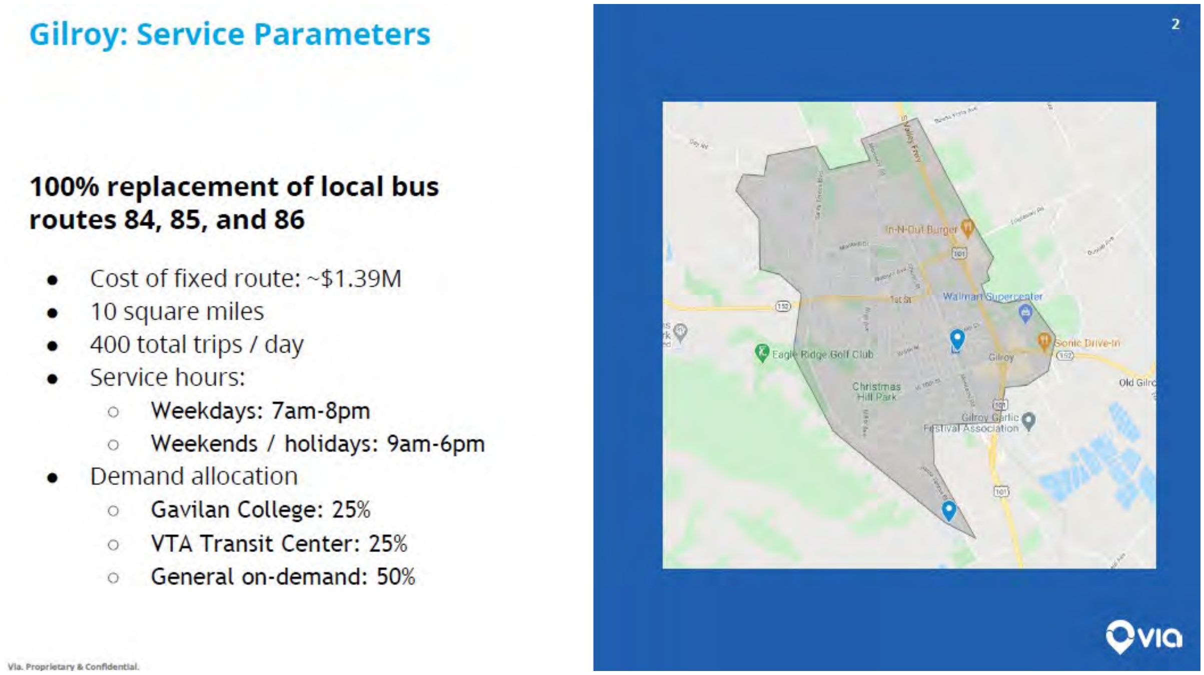
Source: Janice Soriano, "VTA Average Daily Ridership by Stop/Station," https://public.tableau.com/profile/janice.soriano#!/vizhome/SystemwideRidershipbyStop/Dashboard1

The published VTA schedule indicates the two local buses, route 84/85 combined with the number indicating direction, collectively with route 86 make about 80 one way runs per day, at roughly one hour frequencies. Total weekday boardings across all three routes total 400. The average one way run time is 10 to 20 minutes. 80 trips on a weekday multiplied by 15 minutes is 20 hours of vehicle time in service. At $190 per vehicle hour in service, that equals $3,800 per day.

The researchers asked Via staff what microtransit service could be provided for the same $3,800 per day budget within this Gilroy territory, mapped in Figure 32. The cost per trip, for a target of 400 per day, would have to be no more than $9.50 per trip. Service coverage would be the same as the 84, 85, and 86; 7am to 8pm weekdays and 9am to 6pm on Saturday, Sunday and holidays.

Via used its in-house modeling and simulation capability to estimate that as a contractor to VTA there was a good possibility that eight vehicles in an on-demand computer dispatched service could provide up to 400 trips per day. The simulation results are linked to the simulation display in Figure 33.

Figure 32. Specifications for Simulation of Example Gilroy Microtransit Zone

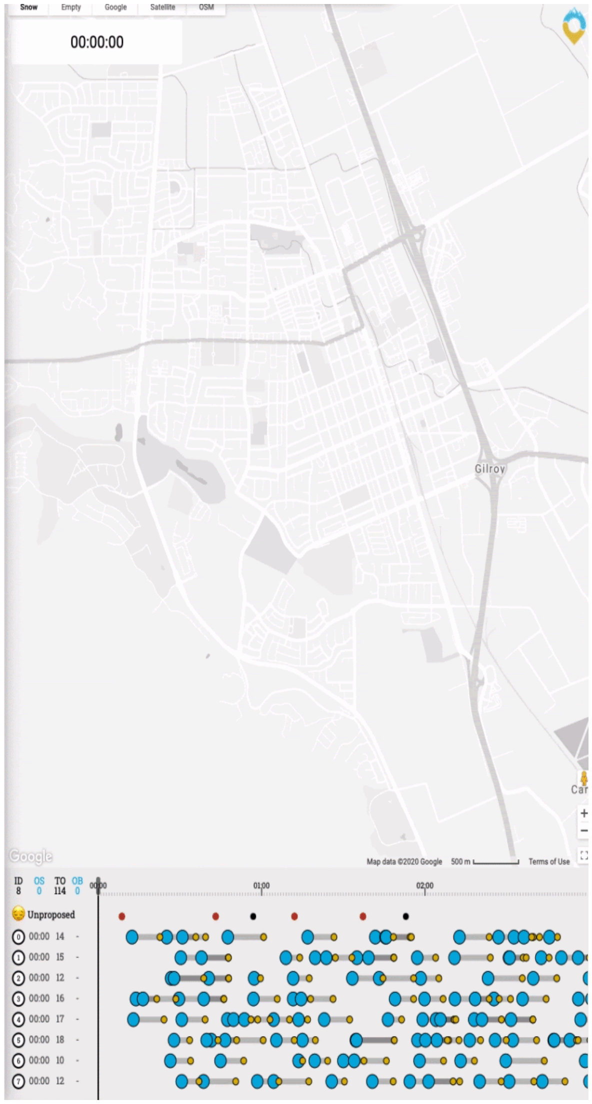


Source: Via, based on specifications prepared by the Ride & Ride research team

A hot link to an animation of the simulation in Figure 33 prepared by private microtransit service vendor Via is at the following link: https://www.dropbox.com/s/v38a1qosjwnn13q/Gilroy-VTAonDemandSimulation.ppsx?dl=0.

To see it operate, download and run the linked file as a presentation in PowerPoint. The proposed service area is from the Ride & Ride research team. This is not a plan or proposal of the VTA transit agency.

Figure 33. Screenshot of Simulation of Hypothetical Microtransit Service Zone in Gilroy



Gilroy: Service Simulation

Number of vehicles	8
Utilization	4-4.5
Average wait time (min)	8-10
Average walking distance (blocks)	1-2
Average ride duration (min)	9-11

Source: Via based on specification from the Ride & Ride research team

The two example simulations of microtransit applied to pre-pandemic ridership characteristics in the VTA service territory revealed potential opportunities for replacing or supplementing existing fixed route service with on-demand service providing equivalent service levels for the same total operating expense in the zone.

There are many adjustments possible within the two simulated plans for a new on-demand microtransit service covering the bus route 27 corridor in south San José, or in transforming fixed route buses in Gilroy to on-demand service.

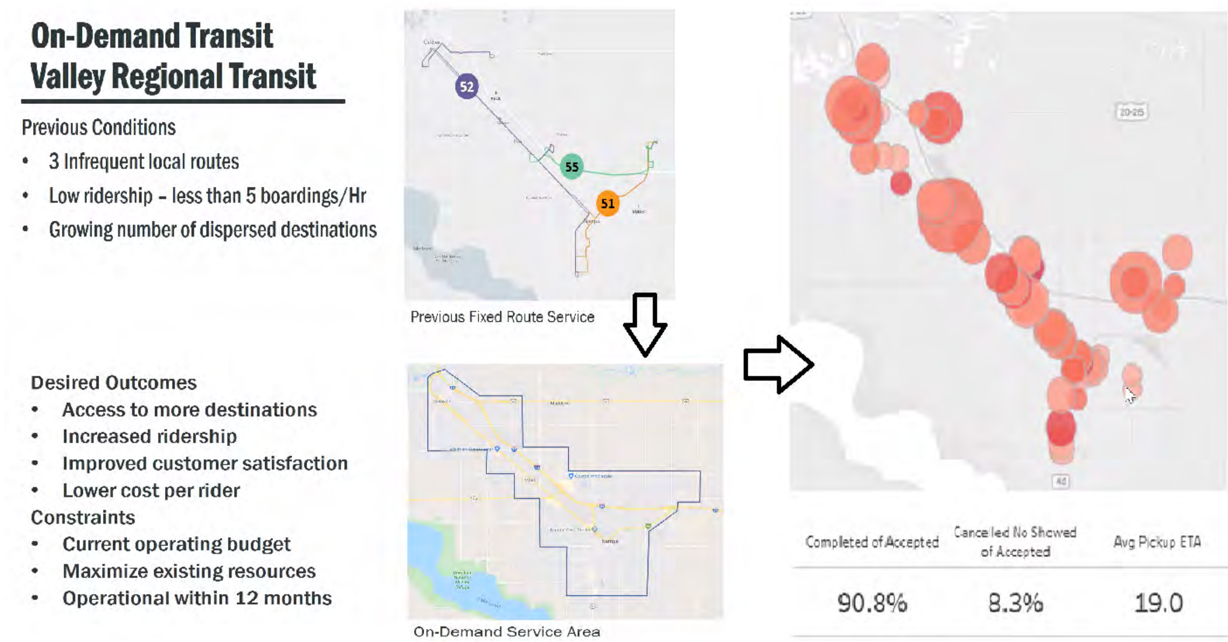
In the simulation, the follow variables can be adjusted to observe the resulting effects:

- Maximum waiting time for customers
- The maximum detour allowed per rider, when comparing the ride to the base rider
- Maximum pickup/drop off walk duration
- Drop off duration; especially important to adjust for non-emergency medical transport and paratransit services
- Allowing doorstep drop offs/pickups
- Defining points of interest/virtual bus stops
- Using weather data to dynamically adjust walking parameters
- Allocating percentages of demand to different points of interest
- Ingesting and taking into account real-time traffic data.

Most of these parameters are for a purely on-demand scenario, and there are additional parameters in the simulation that can be configured for pre-booked rides.

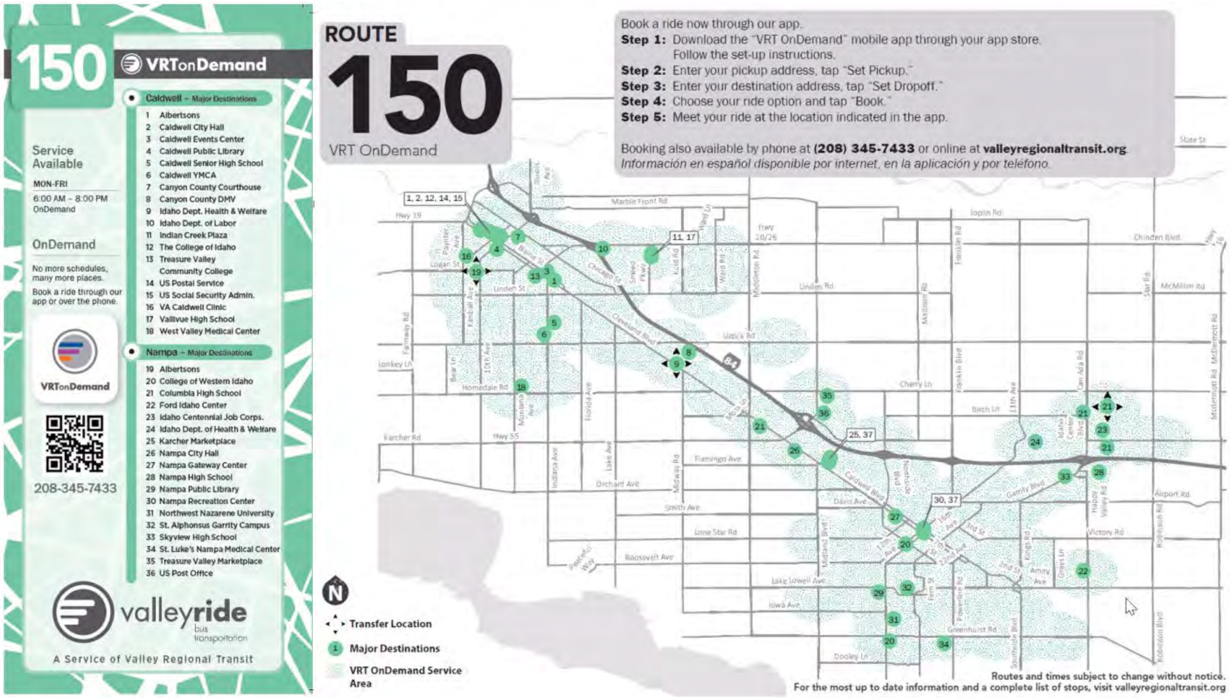
An example of a conversion of fixed route to on-demand that has actually been implemented comes from Boise, Idaho, as established by Valley Regional Transit. Within the level of resources formerly used to operate three fixed routes in a suburban corridor south of Boise, Idaho, the transit agency was able to procure a flexible on-demand service that provided more coverage and increased customer satisfaction.[65] This case is illustrated in the following two graphics showing a suburb of Boise, Idaho. Figure 34 illustrates the planning that began with consideration of three non-productive local routes. The catchment around these routes was expanded, and on-demand pick up points were established throughout this new territory. Figure 35 illustrates how the new on-demand service is described to customers.

Figure 34. Maps and Detail Illustrate the On-Demand Microtransit Service Established in the Boise, Idaho Region



Source: Valley Regional Transit, Boise, Idaho

Figure 35. An Information Document Distributed to Transit Customers in Boise, Idaho about the New “VRT on Demand” Microtransit Service



Note: Customers request rides from and to any points in the shaded areas.
Source: Valley Regional Transit, Boise, Idaho

In a research paper presenting techniques for comparing the cost-effectiveness of demand responsive transit (DRT) and fixed route transit (FRT) in a variety of modeled environments, Edwards and Watkins conclude with examples showing how to determine where there are environments where DRT may be superior to FRT. In particular, these authors suggest that “DRT is more adept at handling the difficulties of servicing a low-density, suburban area than a FRT system.”[66]

Such low-density suburbs are the type of environments shown in the previous examples. The examples described in this section are not conclusive: they come from a vendor with a vested interest in showing the viability of DRT, and from a single newly implemented service in a small Idaho suburb. However, there are many recent examples of agencies in California implementing operational systems, as shown in the next section.

12. Process to Implement Pilot Deployments of General Purpose, On-Demand Microtransit

The transit service improvements within existing budget constraints illustrated in the previous section suggest that there is the possibility for extending the reach of public transit beyond that of typical fixed route hub and feeder system. On-demand microtransit provides universal basic mobility that can be target at geographic zones in the service territory where the demographics indicate that there are mobility disadvantaged customers in need of low-priced mobility. Indeed, since VTA's pioneering efforts in 2016, there are examples of microtransit being implemented in California transit agencies large and small, and sometimes in agency service territory independently from the agency.

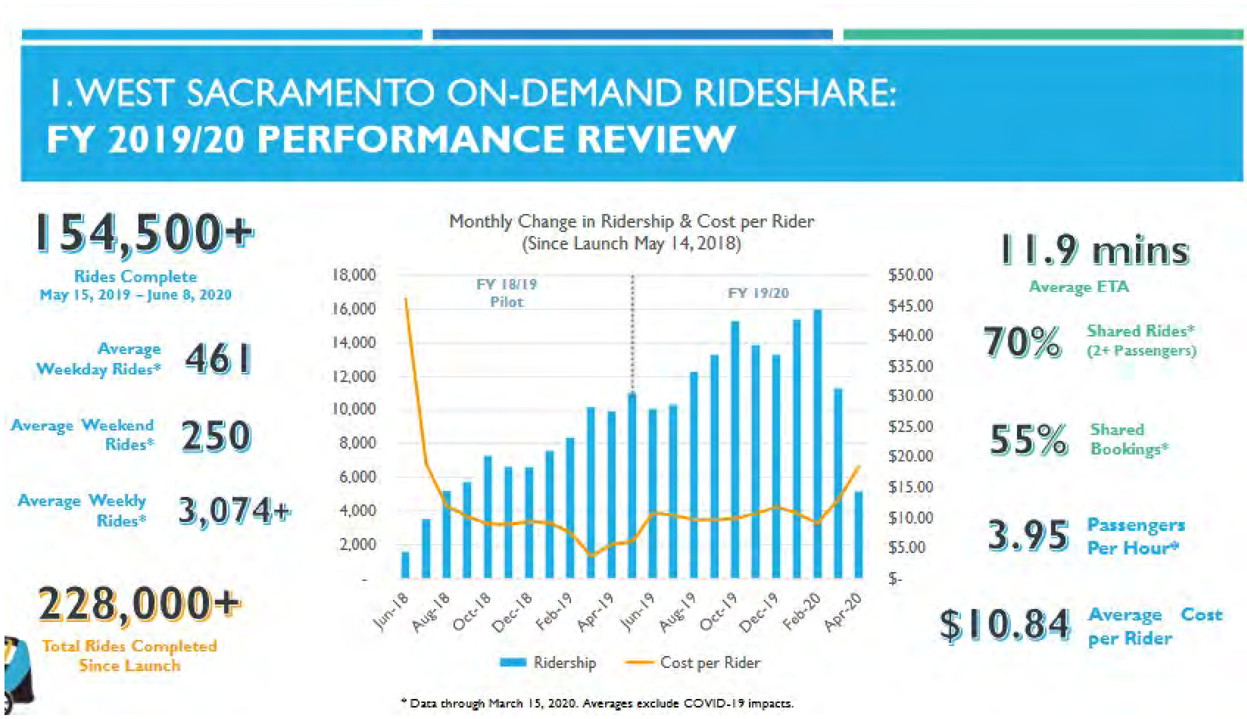
Examples of Microtransit Implementation in California

Sacramento County Transit began its implementation of a modern, smartphone app enabled microtransit by upgrading a long standing dial-a-ride service called "CityRide" in one suburban part of its territory, City of Citrus Heights, which offered rides arranged the day before the day of desired travel. With the vendor Transloc assisting and providing information technology support, even ADA paratransit was included in the service concept, which launched in February 2018 with agency-owned equipment, showing the brand name "SmaRT Ride." The program we well received by customers, with ridership growing, and two more cities added and the fleet expanded. Boardings per revenue hour rose from the 2.25 achieved by CityRide, to 3.6 on average, and as high as four on busy days. The NTD for all of 2019 shows that the agency reported 3.3 boardings per revenue hour for all its demand response modes, which would include some non microtransit paratransit.

The transit advocacy organization TransitCenter criticized microtransit in Sacramento by observing, "Ridership on microtransit in Sacramento peaked at a measly six trips per revenue hour compared to the 10–15 trips per hour the transit industry considers to be a low-performing bus route."[67] However, the agency itself notes its goal to "deliver coverage to underserved, disadvantaged, less-dense communities and provide connections to the rest of the SacRT system," and also to "gather feedback on how the region would prefer to allocate transit resources, understanding that although microtransit cannot achieve high ridership relative to fixed route service levels, it provides flexibility and convenience, which are highly desirable to many riders."[68] The service has been expanded since 2018 to cover nine service zones, launched in January 2020 with Via's technology guiding 45 shuttles, nine of which are zero-emission electric vehicles.[69] The service has held up in the pandemic, even doubling 2019 ridership from around 10,000 per month to over 20,000 per month in 2020 according to the NTD boarding reports.

The City of West Sacramento, located across the river from the state capital and within the service territory of the Yolo County Transportation District (YCTD), arranged with Via in 2018, to establish an on-demand service covering the entire city, with stop locations within two blocks of all locations. As described in Figure 36, boardings per vehicle hour were reported by the city to have reached 3.95 before the pandemic struck and then service and ridership dropped. The contract with Via for service has been extended through June 2022, and there is high user and sponsor satisfaction. There is no federal involvement, so the service performance is not included in the NTD.

Figure 36. Statistics Describing Demand-Responsive Microtransit Performance in City of West Sacramento



Source: City of West Sacramento, "Updates on the West Sacramento On-Demand Rideshare Service," slide 4, https://www.cityofwestsacramento.org/home/showpublisheddocument?id=11160

As a third example from California, AC Transit in Alameda has implemented an on-demand service called Flex in two geographic areas, Newark and Castro Valley, allowing for the elimination of three fixed route bus lines.[70] This service has been suspended as of February 2021 due to the pandemic.[71] As of May 2019, the agency reported, "[t]hese zones are currently averaging four boardings per hour; the transit agency feels that when a fixed route is between 6–10 boardings per hour it merits consideration of transitioning to DRT [demand responsive transit]. Ridership on the microtransit services is around 20% lower than the fixed route service it replaced."[72]

Los Angeles County Metro implemented a microtransit service called Metro Micro in five zones, Watts/Willowbrook, LAX/Inglewood, North Hollywood/Burbank, Compton/Artesia and El Monte in December 2020. Four more service zones are planned for later in 2021. These zones are aligned with changes in bus service called NextGen, and always include stops at rail stations. Metro wants the service to be mostly about FMLM access for rail and bus customers, although any origins and destinations within a zone are acceptable. The service is provided through a contract with microtransit vendor RideCo, procured competitively. The van vehicles can handle wheelchairs and have a bike rack on the front. The introductory fare is just $1, paid through an app or by tapping a card reader in the vehicle.

From January 2019 there was a similar microtransit project in three demographically similar zones, focused more directly on station access at Artesia, El Monte, and North Hollywood, with the vendor Via that had been engaged with available federal funding. A formal procurement process that pitted RideCo against Via and others had begun in 2017, and by early 2020, based on working closely with both these vendors, and others, RideCo was selected.[73] LA Metro documented that RideCo was better able to integrate its services with the agency's plans for how microtransit fit into its overall fixed route network. Via operated its microtransit service through July 2020, with ridership growth maintained as described earlier in Section 3.

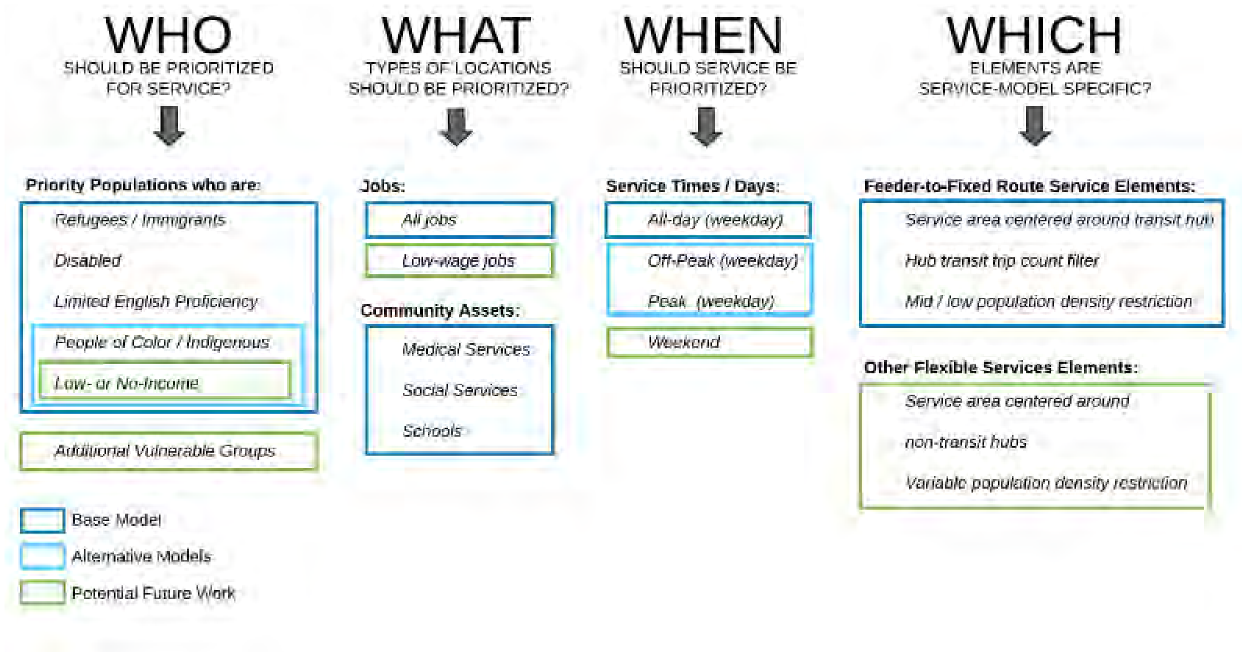
Other microtransit implementations for public transit agencies are operating as of April 2021 in Bakersfield, Anaheim, Porterville, Marin County, and Antelope Valley.[74]

Current best practice approaches by transit agencies includes maintaining an ongoing consultation process with community members who are existing customers or potential customers of the agency's services. Consultation with transit users should be part of an inclusive process in the planning of microtransit, as illustrated in the efforts of the "Transit Planning 4 All" project sponsored by the United States Department of Health and Human Services' Administration for Community Living in collaboration with the USDOT Federal Transit Administration.[75]

Two tasks for an agency moving forward with implementing DRT, are deciding *where* in the territory to implement it and *procuring* the expertise to implement.

For example, in deciding where to offer FMLM on-demand microtransit, King County Metro in Seattle is beginning to use a sophisticated process by Cowick and Munkel for targeting economically disadvantaged populations who are mobility disadvantaged as well,[76] as summarized in Figure 37.

Figure 37. Example of Transit Agency Policy Questions Guiding Planning Analysis of On-Demand Microtransit Services



Source: King County Metro Transit (Seattle), Cowick and Munkel, 2020

Best Practices in MOD Implementation

As noted in Section 6, and shown in the previous examples in this section, most forms of MOD have been contracted to the private sector. Available documentation is clear that the private sector has growing, changing, and improving capabilities in supporting microtransit design and implementation.

In the process of implementing MOD, the following procurement steps are derived from those implied in the guidelines from Transit Cooperative Research Program (TCRP) Synthesis 141, "Microtransit or General Public Demand Response Transit Services: State of the Practice"[77] and those recommended in the guidelines from research at Eno Foundation.[78]

One reasonable practice is paying for short sales consultations by the top three vendors determined in a formal request for information (RFI) screening. The agency should make clear that negotiations for the purchase of service could follow with zero to three of the firms engaged in the consultations, plus any additional proposers. The meeting results should be documented and made transparent to the microtransit industry and the public. The typical public sector competitive process rules need to be observed once a formal procurement is underway, and the agency needs the ability to choose the best value combining a judgment on vendors' competence as well as price.

The agency must define the service goals, which are best stated as simply as possible. As one good example of scope, consider the goals laid out after a pre-procurement learning process by Valley

Regional Transit in Idaho in a formal request for proposal (RFP) issued for the suburban part of its territory as previously described.[79]

> STATEMENT OF OBJECTIVE
>
> Valley Regional Transit (VRT) is seeking proposals from private companies to develop and implement a pilot for a modern and innovative transit on-demand system in Nampa and Caldwell Idaho. VRT is interested in developing a transit on-demand system that can leverage current capital resources, e.g. existing vehicles, bus stops and shelters, and existing staff, to deliver a comprehensive, high quality, and sustainable transit on-demand solution within current financial constraints. VRT is the Regional Transit Authority for Ada and Canyon County with a vision of expanding transit solutions in one of the fastest growing regions in the country. If successful, there would be interest in expanding transit on-demand solutions for other services and to other parts of VRT's service area. At a minimum the system should have the following characteristics:
>
> • Intuitive and easy to use mobile app, on-line access, accommodate walk-up riders, as well as a landline phone option
>
> • Flexible, frequent and reliable services
>
> • Support key activity areas in the cities of Nampa and Caldwell, as well as educational institutions, dense areas, and employment centers
>
> • Agency and customer support
>
> • Comprehensive real-time data reporting
>
> • Implementable within the existing time constraints
>
> • Compatible with existing fare collection systems
>
> • Capable of carrying more than 10 passengers per revenue hour
>
> • Effective marketing tools, resources and outreach support to implement service.

As illustrated in the Boise example, the RFP issued to the world of potential vendors covers the refined objectives, rather than a detailed scope of work. The key assets the private sector would bring to the agency would be ride ordering, dispatch, and fleet management software application. The vehicles, drivers and fleet management skills could potentially come from the agency or the vendor.

Once the microtransit service is operating, the ability to make service adjustments quickly is important, as actual operating experience and customer response is observed and measured.

A potential add-on to secure the most value from resources, is a flexible process to subsidize existing private sector mobility providers such as taxis and TNCs for service coverage of low-demand time periods and days, or even during normal weekday business hours if they are an agency-approved means of providing quality alternative services in particular circumstances. These subsidies should be considered within the overall budget constraints. One means to manage subsidies efficiently is micro-subsidy determination and delivery through wireless and cloud computing as described by Niles and subsequently being developed in Europe as in Rideal.[80, 81]

13. On-Demand Microtransit Serving All Customers

In regions where customer density is not sufficient for fixed route transit services, an on-demand transit service can serve a higher number of potential customers per acre of service area, providing a goal of transit agencies seeking to provide social equity in their program. One method of aggregating customers is to serve riders across the many categories that merge demographics with trip purpose. For instance, agencies can examine the categories of customers currently defined as "special needs," especially mobility impaired and seniors, the traditional province of dial-a-ride paratransit, and those needing transport for medical care.

Paratransit customers eligible for transit equivalent service under the Americans with Disabilities Act (ADA) and Medicaid clients eligible for fare-free non-emergency medical transport are two groups of customer for on-demand mobility services that are currently treated as special categories, with extensive regulations that provide barriers to transit agencies serving them via general purpose mobility on demand. However, there is potential for improvements in transport efficiency with the opportunity of attracting some members from these two categories into general purpose MOD for travel in zones where it is offered.

Under the Federal ADA regulations, all transit agencies offering fixed route transit must offer vehicle service at the curb for eligible persons with disabilities who are within three quarters of a mile of fixed route transit access, but who are not sufficiently ambulatory to walk to a fixed route transit stop. The destination must be within the same distance from an ordinary fixed route stop. Wheelchair compatible vehicles are normally provided, whether or not the customer is using one, and the driver usually helps with loading and unloading. The rides are usually required to be scheduled at least a day in advance, but in some agencies, same day scheduling is allowed. The use of general purpose on-demand transport, when and where compatible with the travelers' ambulatory capabilities, could provide better service at a lower cost than the typically expensive ride services of ADA paratransit.

Across the U.S. the NTD reports that overall the average on-demand paratransit cost is $45 per passenger boarding, compared to bus boardings with average cost per boarding of five dollars, in 2019. The 2019 total operating cost of U.S. paratransit was four billion dollars, divided across an array of private sector providers. Reducing the costs by 20%, to $36 per passenger, by moving a fraction of the most ambulatory paratransit customers to general purpose on-demand microtransit dispatched with modernized on-line scheduling would result in an $800 million national saving, an aspirational target, but resulting in a positive outcome, even if only partially achieved. However, reaching this vision requires that the summation of all the fixed costs of existing paratransit systems could be reduced by efficiencies resulting from the amalgamation of operations region by region.

In the second category, Medi-Cal, the California system of Medicaid, provides reimbursement for client travel in support of their healthcare. As a policy, the system wants as many of its clients as possible to travel "by ordinary means of public and private conveyance" unless "medically contra-indicated."[82]

Combining all categories of customers requiring wheelchair capable vehicles for a transit trip into one combined service category covering ADA and NEMT for any trip purpose may lead to economies of scale in regional markets. In fact, experience in California, and other parts of the country, shows that an on-demand ride service can be melded with the paratransit requirements set by the ADA and familiar to public transit agencies, and with NEMT. This integration is supported by the federal policy guidance established by the Federal Coordinating Council on Access and Mobility (CCAM) which states that "Federal grantees should coordinate their transportation resources where possible, including sharing costs for mutually beneficial transportation services, to maximize the availability and efficiency of transportation services. Cost-sharing arrangements include vehicle sharing and ride sharing as well as Federal fund braiding for local match across Federal programs."

For example, Via has been contracted by the public transit agency in Bakersfield, CA to merge paratransit, NEMT, and a new on-demand zone service. According to the vendor, the service has been able to:

- Allow for fleet sharing to reduce the number of vehicles needed across all three services, thus improving utilization
- Swap vehicles and drivers as needed between services
- Be able, as public health rules allow, to have customers from different services share rides for overall cost-efficiency of the transit agency
- Reduce training time and the number of dispatchers needed
- Eliminate having to change between three on-line platforms, reducing error rates
- Quickly identify which services any unique rider is eligible for, allowing dispatchers to easily toggle rider eligibility and coding for any of the services offered
- Create a unified marketing and rider education campaign around one app
- Avoid confusion and complexity by providing riders with the one single app for all services, plus an alternative call-in booking method for those without a smartphone.[83]

As a second example, an academic paper published in 2020 examined the potential for general purpose microtransit serving some trips of ADA-eligible paratransit customers in Arlington, Texas, and found an opportunity for cost savings and more convenient service.[84]

Beyond customers who use ADA paratransit and NEMT, there are a variety of trip purposes sought by seniors, low-income individuals, and other mobility disadvantaged individuals who seek to go to places where fixed route transit does not serve.

In response to this need, as a requirement of federal law, the Bay Area Metropolitan Transportation Commission publishes a Coordinated Public Transit Human Services Transportation Plan, with the most recent version published in February 2018. This plan asks the question, "[h]ow can MTC and its partners provide mobility options for seniors, people with disabilities, veterans, and people with low incomes that are also cost efficient for the region?"[85]

The Coordinated Plan envisions a cost-effective expansion of services for these customers. Table 10 shows the list of existing services targeted at the named groups.

Table 10. Services and Markets in the Bay Area's Coordinated Public Transit Human Services Transportation Plan

Existing Targeted Services	Seniors	People with Disabilities	Veterans	Low-Income Populations
Fixed-route transit	✓	✓	✓	✓
ADA-mandated paratransit		✓		
Community-based shuttles	✓	✓	✓	✓
Private demand-response transportation	✓	✓	✓	✓
Subsidized fare or voucher programs	✓	✓		✓
Volunteer driver programs	✓		✓	
Information and referral	✓	✓	✓	✓
Travel training	✓	✓		
Mobility management	✓	✓	✓	✓

Source: Bay Area Metropolitan Transportation Commission, https://mtc.ca.gov/sites/default/files/MTC_Coordinated_Plan.pdf

General purpose, on-demand microtransit would clearly fit in the lefthand column and provide a new option. Examinations of demograpic data provides information to planners on areas with the most potential riders of general purpose DRT.

Mobility management of the "targeted services" in Table 10 can include volunteer services which can supplement capacity when agency microtransit is overloaded or not in service. Referrals can be made to ride services offered by the non-profit sector utilizing volunteers. For example, the Ride & Ride research team found this description of volunteer driver programs in Santa Clara County: "[l]ast year, an estimated 14,000 rides were provided by volunteer drivers from programs at Avenidas, R.Y.D.E. (five west county cities), Heart of the Valley, Portuguese Organization for

Social Services and Opportunities, and the City of Morgan Hill's pilot program: Getting Around Town."[86]

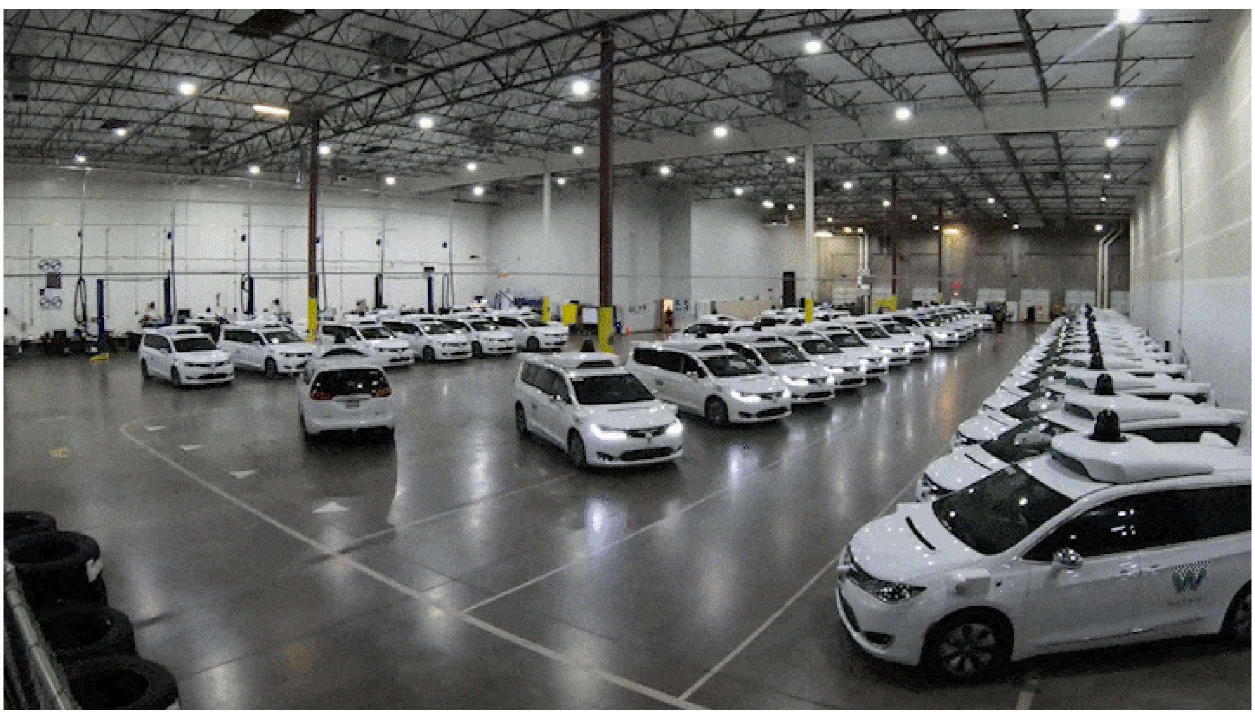
Excessively dividing regional customers into multiple special needs categories based on the fragmented evolution of past practice—each category requiring a different mobility service response—is detrimental to the efficiency of publicly funded mobility. Such sub-categories also weaken requests for funding in the competitive allocation of resources to all community needs that cover far more than mobility. Merging paratransit, health care NEMT services, and all other mobility needs, into an agency program for universal basic mobility is an important step in pushing general purpose on-demand microtransit to efficiency levels that justify its existence. Such a merged service can be integrated across all classifications of passengers, but with a geographic and demographic outreach emphasis on population segments that do not have the household resources for personal self-reliance using private vehicles and commercial on-demand options such as taxicabs.

14. Implications of Vehicles' Automated Operation

Automation is an evolving characteristic of vehicle control that will change the responsibilities of human attendants assisting customers as part of service delivery, and in fact contribute to decreased costs per trip. There is vast private sector interest in creating driverless ride service vehicles of all sizes, which would in theory reduce the cost of service by half or more. The potential of automated operation is a form of future cost reduction in on-demand microtransit services that are currently operated by human drivers.

As noted in the textbook by Grush and Niles, these robotaxi vehicles are the potential microtransit vehicles of the future.[87] An early version of such a service using Chrysler–Pacifica hybrid vans has been in limited driverless operations with paying customers in a well mapped, geo-fenced area of the Phoenix suburbs since October 2020. Figure 38 shows the vehicles in the fleet service facility.

Figure 38. Storage Area of Waymo's Operational Robotaxi Fleet in the Suburbs of Phoenix, Arizona



Source: https://blog.waymo.com/2019/08/getting-ready-for-more-early-riders-in.html

On-demand, small vehicle, transit agency feeder service in replacement of legacy fixed route lines is more expensive now than it could be in the future due to the current requirement for human drivers. Automated control of vehicles holds the potential for reducing the per trip operational costs by eliminating the wages of professional drivers. As an example of transit agency cost structure, the buses of VTA operated at a cost of $195 per service hour in 2019. This cost covers drivers, maintenance, supervision, and fuel. Forty percent of the cost, $79 per hour of each bus in service, is expended in compensation for drivers, including wages, vacation pay, and other benefits. Eliminating this 40 percent cost component implies—with many assumptions—that driverless operations would cost less than what operations with human driven vehicles cost. These assumptions include a decreasing future costs experience curve for automated vehicles' hardware and software requirements, supportive infrastructure outside the vehicle, and human oversight of automated fleets. There is uncertainty in forecasting these costs, but growing cost-effectiveness is a goal of many large companies, each underway investing billions of dollars. Robotic, small-vehicle public transit is the potential outcome.

Another way to look at the cost of drivers is to compare the $1.40 operating cost of U.S. buses per passenger-mile with the 14 cents per passenger mile for van pool vehicles, where the driver is one of the passengers commuting to a work destination along with the other passengers and is only compensated in some systems by being allowed to use the van on weekends. That reduces costs without a paid driver to ten percent of the cost when a licensed professional driver is in control. Costs for automated operations and of automated vehicles are likely to drop as experience grows and as the best performing technology applications are standardized.

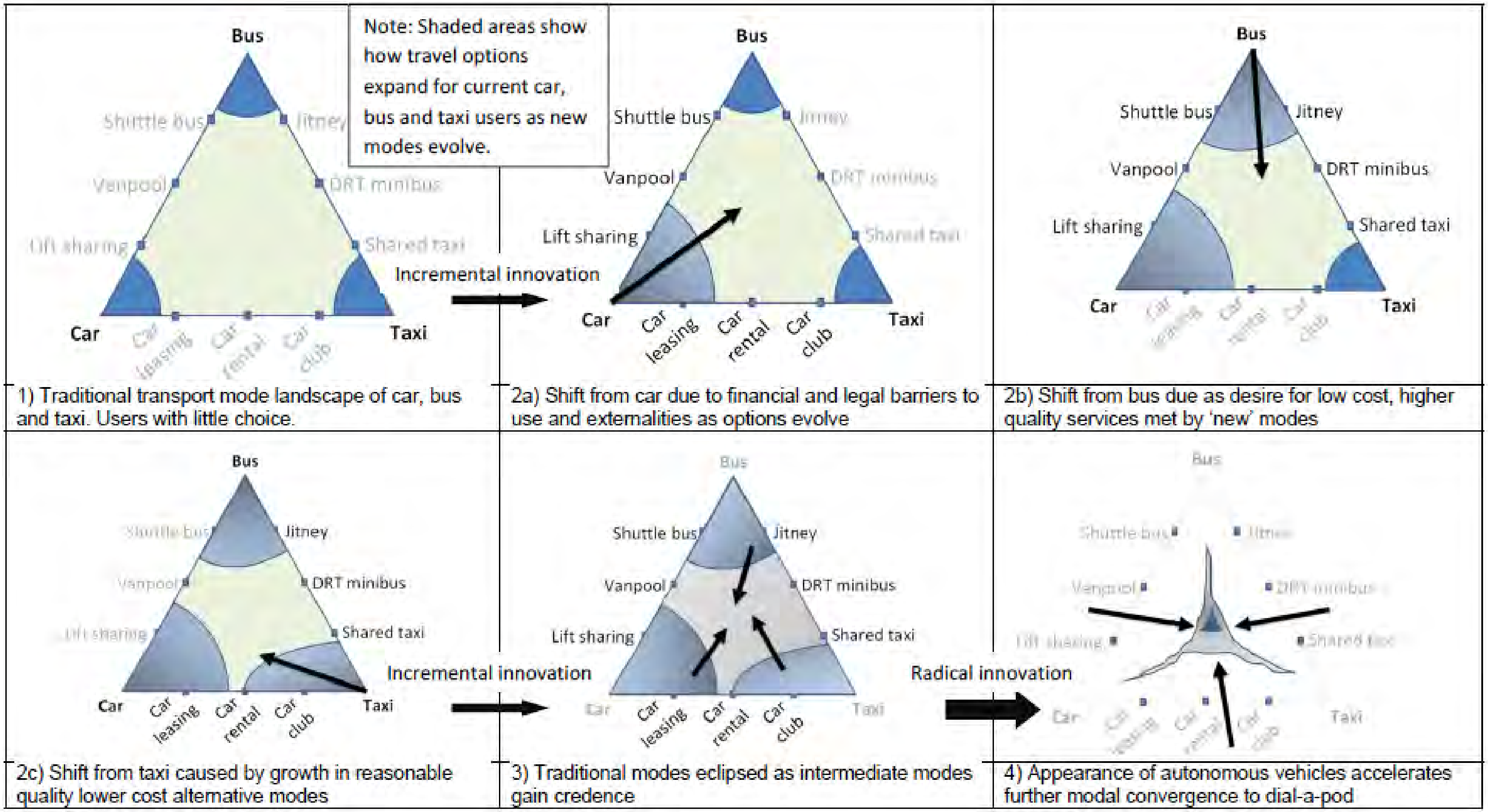
The potential for the evolution of three legacy urban road modes into "dial-a-pod" robotaxis (as seen later in Figure 40 and Figure 44) was forecast by Enoch in 2015 and illustrated concisely in Figure 39. Enoch developed a sequence of likely steps that would lead to the convergence of bus, private automobile, and taxi modes into a new robotic taxi/shuttle mode, consistent with the analysis of Grush and Niles.[88] As Enoch noted,

> *These developments are being driven by both technology-push and demand-pull factors including: the development of the internet, smartphones and locational trackers and the increasing automation of the motor vehicle; the perceived threats of climate change, energy security, the global economy and the idea of increased choice; the goals of reducing public spending and of mitigating congestion levels; and demographic factors such as an ageing population and suburbanisation; changing attitudes towards issues such as sustainability, working, privacy and ownership.*[89]

Most important in the present day is that the level of demand for on-request microtransit rides can be tested in any transit territory with human drivers. If well used, then automated vehicles are in position to be phased in, just as seen in the process of customer familiarization that is now underway with the Waymo robotaxi service in the Phoenix suburb of Chandler. If government-subsidized human driven microtransit is not well accepted by travelers currently, there is diminished reason to believe that automated operation will make the service more popular.

If well used in today's pre-automation and pending-automation era, the type of motorized, on-demand feeder service driven by humans and described in this research would predict the viability of switching from human operated to automated feeder service, once driverless vehicle control is shown to operate as safely and as reliably as human driven vans. Automating on-demand flexibly routed feeders capable of operating in general purpose road traffic (for example, the fleet shown in Figure 38) is one important path to better public transit service and increased ridership.

Figure 39. A Model of how Local Passenger Transport Modes Could Evolve into Automated Taxis



Source: M.P. Enoch

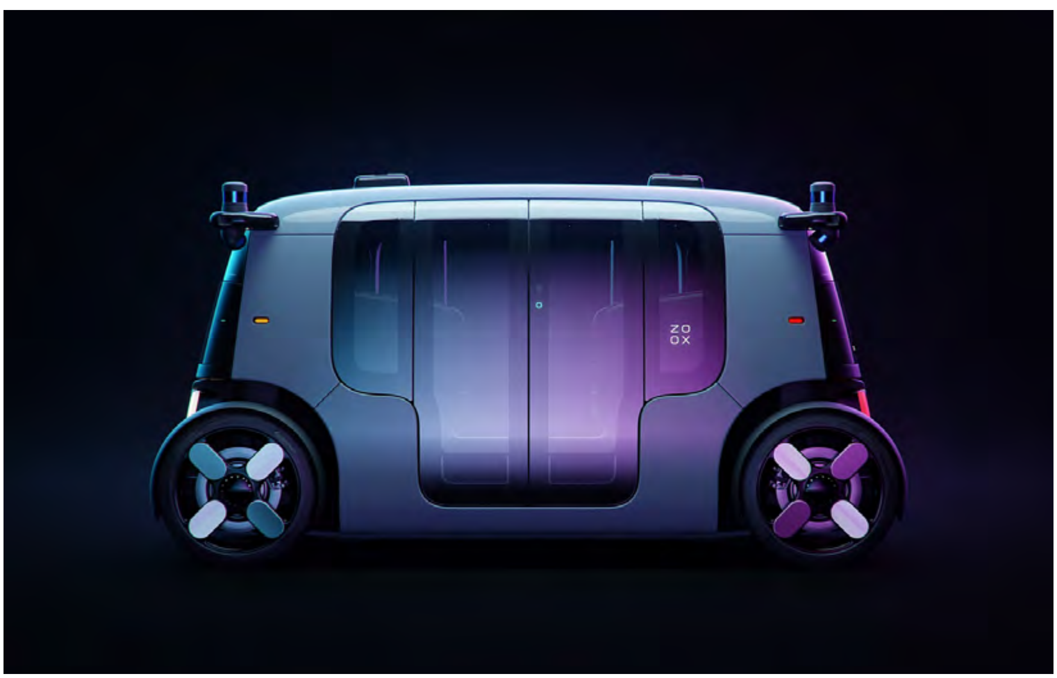
15. Electrification to Reduce Air Emissions

To support the reduction of both air pollution and greenhouse gases—two significant justifications for government investment in public transit—the Ride & Ride research team joins with the consensus of many governments and transportation industry firms worldwide to urge the application of quiet, non-emitting electric propulsion to the road transit vehicles that provide on-demand, microtransit rides for customers in all markets. Especially as from April 2021, the expansion of electric vehicle usage in all types of road vehicles is a U.S. Presidential priority.[90]

In California, in support of air quality, climate, noise control, pollution control in storm water runoff, and environmental sustainability generally, electric vehicle are preferred for passenger transport, provided they permit a total life cycle cost that is financially acceptable. Electric vehicle fleets are used in some existing microtransit programs, and the future is promising for improved vehicles appropriate for microtransit. Examples include all-electric microtransit services in pilot exploration in the City of Anaheim and Fresno County.[91, 92]

Developers of future driverless passenger vehicles for on-demand ride services are fully committed to electric propulsion, with pod-looking examples having no operator controls shown in the Figure 40 depiction of the Amazon Zoox and in the pandemic-safe interior design of the GM Cruise Origin in Figure 44.

Figure 40. Electric Robotaxi Prototype by Zoox, a Subsidiary of Amazon



Source: Zoox home page photo, https://Zoox.com

16. Simulation Tools

The operation of transit services, whether on fixed route networks or on-demand with variable routing along a street network, can now be simulated in computer models that allow for an array of characteristics of the vehicles, the customers, and the environment, all to be observed before choices are made on how the vehicles will be implemented. As simulation vendor BestMile's CEO has written:

> *Hitting the streets to see how a mobility service works is an expensive way to learn, especially when the lesson is that the service doesn't work. One way to get micro-transit and other services like it right is to use data and analytics to test services in advance by using existing ride matching and dispatching algorithms. It is possible to simulate how services might perform in advance of deployment, giving planners and operators invaluable information to help increase the odds of success.*[93]

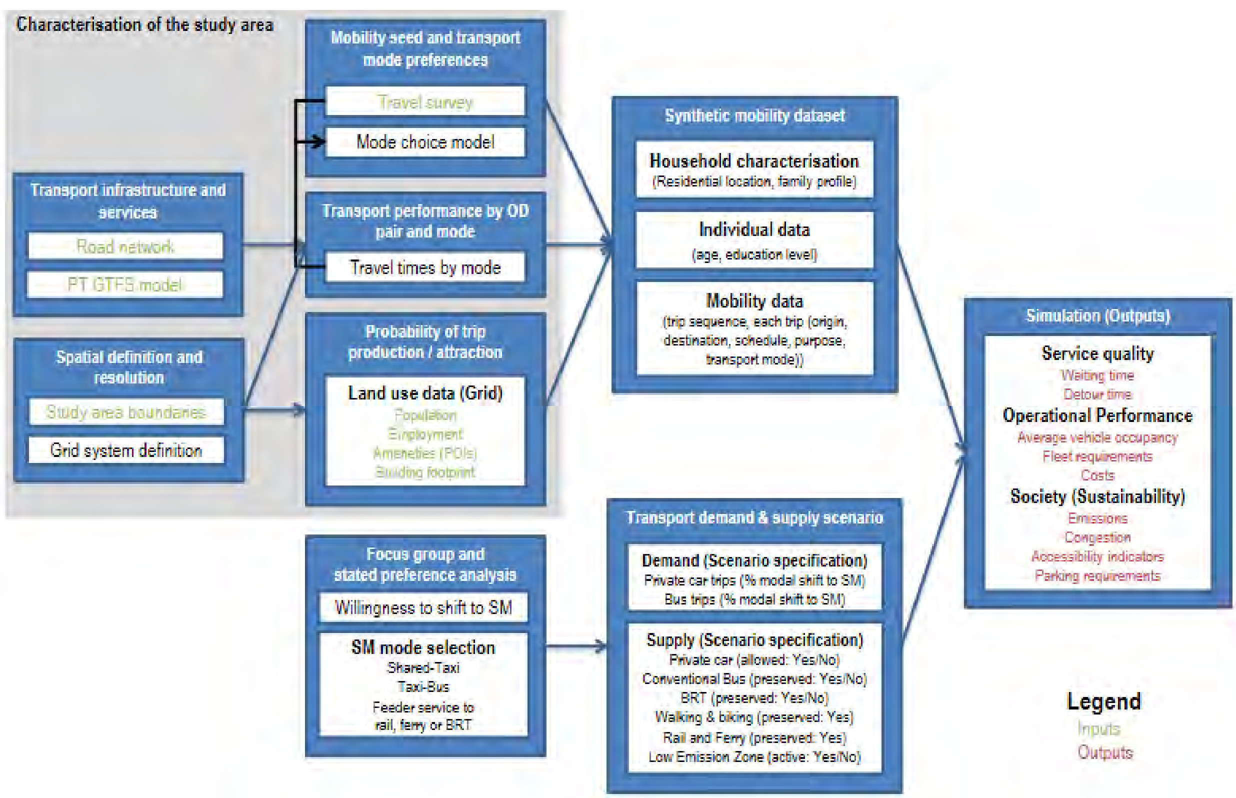
For example, Chow and colleagues at New York University used a public domain software package to develop a computerized model of a corridor in the Bronx borough of New York City, that could illustrate the operation of fixed route, flexible routing with deviations, and door-to-door on demand, with operating rules for each service pattern. A data set was synthesized with stop level origin and destination recorded in a survey of passengers on the Metropolitan Transit Authority B63 bus. Inputs included customers' travel demand per hour, capacity of the vehicles, and the number of them in the fleet. The model computed wait time, walking time, riding time, average complete trip travel time, and vehicle mileage. In the example, customer travel time for the door-to-door service was lowest across the three service types, but the vehicle mileage was highest. The researchers at NYU point out that

> *A combination of multiple types of real-time information on passenger counts, traffic status, road conditions, and system performance can be used by traffic operators in deciding the operations, network planning, scheduling and control of vehicles under dynamic environment.... Some strategies may include planning dynamic and automated vehicle dispatching system, developing schedules responding to user demand, adjusting headway and frequencies as per passenger load patterns, implementing vehicle operation control and holding strategies, monitoring service quality, and coordinating with ITS technology for signal prioritization for transit vehicles. The real-time information on demand and supply side can be used effectively for adjusting the service and for managing the demand.*[94]

We also reviewed the BA-MATSim computer based model developed at the Institute of Transportation Studies, University of California, Davis. A 2020 Mineta Institute study utilized the BA-MATSim model to depict how many rides in the San Francisco Bay Area could demand and be provided with an automated on-demand service utilizing 5,000 eight passenger vehicles picking up and dropping off passengers requesting rides to a BART rapid rail station from designated points within a two minute walk of each riders' home.[95] Multiple passengers would be carried when served riders going to the same BART station were starting out close by. Different fares were modeled. At a fare of $2.50, in a three hour morning peak period, 15,000 vehicle hours served 57,000 riders, which equates to 3.8 riders per vehicle-hour.

There is more powerful evidence from previous computer simulations of urban mobility in existing cities that on-demand, shared ride vehicles working in combination with trunk transit lines could serve most of the mobility demand now served with private automobiles. Figure 41, from a study by the International Transport Forum (ITF) of the international Organization for Economic Co-operation and Development (OECD), about the effectiveness of shared mobility in Lyon, France is an important recent example. It builds on earlier work in Auckland, Helsinki, and Dublin.

Figure 41. The Building Blocks for the Shared Mobility Model from the International Transport Forum



Notes: PT- public transport; OD – origin-destination; SM – shared mobility.

Source: ITF "Shared Mobility Simulations for Auckland," International Transport Forum Policy Papers, No. 40, OECD Publishing, Paris, 2017, http://dx.doi.org/10.1787/5423af87-en

The ITF, in summarizing the Lyon analysis reports,

> *The current mobility demand in the Lyon metropolitan region could be met almost entirely by shared mobility and present public transport systems, reducing private vehicles to only 5% of the modal share, all of which would be used for carpooling. …Were the city to replace underused and inefficient bus routes with a taxi-bus system, this and other shared mobility services could become feeders to public transport, reducing private car use by 20% and resulting in a 12% reduction of CO2 emissions and a 16% reduction in congestion.*[96]

The two simulations described earlier developed by Via, at the request of the researchers in this project, determined optimum fleet size for low-capacity, van-type on-demand rides in service areas of approximately 20 square miles or less. Via's was not a demand-forecasting model, but is designed for logistics planning when patterns of origins and destinations are known for a specific demand level. Parameters included waiting times, locations of most common destinations, frequency of requests by hour of day, locations of pick-up/drop-off points, and fleet specifications.

The operation of passenger carrying, on-demand microtransit services described in this research can be simulated in computerized systems such as those described here, or others that are similar. Other industries have characterized on-going, stand-by computer simulations of physical systems as "digital twins." As described by the Transportation Research Board Standing Committee ADB20 on the Effects of Information and Communication Technologies (ICT) on Travel Choices:

> *Digital twins refer to digital (simulated) environments that mimic completely the behavior of the actual systems, allowing the testing of policies and strategies in the same form as would be deployed in the corresponding real-world system. The term also includes digital counterparts of the users, capable of interacting with suitable systems. Such interactions may involve acting on behalf of the user, e.g., initiating shopping, or making decisions regarding travel arrangements, thus effectively emulating (or possibly enhancing) human behaviors. Implications for mobility are likely to be substantial, though still largely uncertain in their nature.*[97]

It would be useful in such digital twin simulations to understand the degree to which mobility disadvantaged citizens were located to assess priorities for service enhancement. The Ride & Ride research team read a well-documented case study which described the incorporation of demographic data in simulations using agent based modeling to revise a bus network in a suburb of Catania, Italy from completely fixed route to a combination of fixed and demand responsive shared transit.[98]

The private firm, Streetlight Data, introduced a data platform in February 2021, that recreates the movement of all transportation modes in cities across America, using anonymized data from cell phones and vehicle tracking systems built into newer cars.[99] This data provides counts of travelers across all modes, including buses, trains, cars, bicycles, and walking. This firm can provide validated estimates of traveler count data on origins and destinations of travelers by time of day across all modes. This firm has a partnership with the simulation company PTV and claims to be able to build a digital twin of a transit network that would allow testing of alternative configurations.

In the Ride & Ride research team's review of possibilities, it was found that demographic survey results from the ongoing American Community Survey of the Census provided demographic data on senior population, disabled, low-income, and vehicle ownership at levels of detail required to support targeting of enhanced service through demand response, as shown in Figure 24 for light rail stops in San José and in Figure 30 for the Gilroy area of VTA territory. This data can be layered into a digital twin.

Another important goal for maintaining digital twins of transit operations is to make sense of microtransit vendor claims, such as Via's claim that their service in Arlington, Texas "has reduced congestion in the city by more than 400,000 vehicle miles, representing a 36% reduction in total vehicle miles traveled for those passengers."[100] This claim is subject to many interpretations.

The cost of developing and institutionalizing ongoing digital twin simulations is certainly more expensive than individual U.S. transit agencies can currently afford, but the benefits are significant enough that setting up the capability should be explored in California with the sense that costs of implementation of such a decision supporting system are on a path to become less costly over time as software tools are developed. Argonne National Laboratory is developing affordable regional simulations with federal resources in cooperation with transit officials in Chicago and other cities.[101] The City of Wellington, New Zealand, with assistance from its national government, has implemented a digital twin of the city displaying many functions, including traffic and transit, shown in Figure 42, illustrating the photo realism in the presentations to users. Some operational and historical data measuring transit performance is currently available, and more capabilities are being added year by year.

Figure 42. Screen from City of Wellington's Digital Twin, Displaying Public Transport Functionality as Animation

Source: Sean Audain, City Innovation Lead, Wellington City Council, "Place Matters: How Cities Can Compete in the Next Future of Work Paradigm," Meeting of the Minds webinar, April 21, 2021, https://meetingoftheminds.org/cal/place-matters

Potentials in California for developing this kind analytical work include the larger metropolitan planning organizations, such as the Metropolitan Transportation Commission of the Association of Bay Area Governments and the Southern California Association of Governments, with the support and participation by the California Transit Association, the Mass Transit Division of Caltrans, and transportation focused institutes within the California higher education system.

17. Response to COVID-19

The risk exists that the effects of the pandemic may continue throughout 2021, into 2022 and beyond.[102] The bond rating agency Moody's is forecasting a permanent 20% reduction in transit ridership in New York City, London, Paris, and Vancouver, BC.[103] The negative attitude of consumers toward riding in the enclosed space of a bus is at risk continue (Figure 43).

Figure 43. Sample of Attitudes toward Buses Mapped Before and During the Pandemic

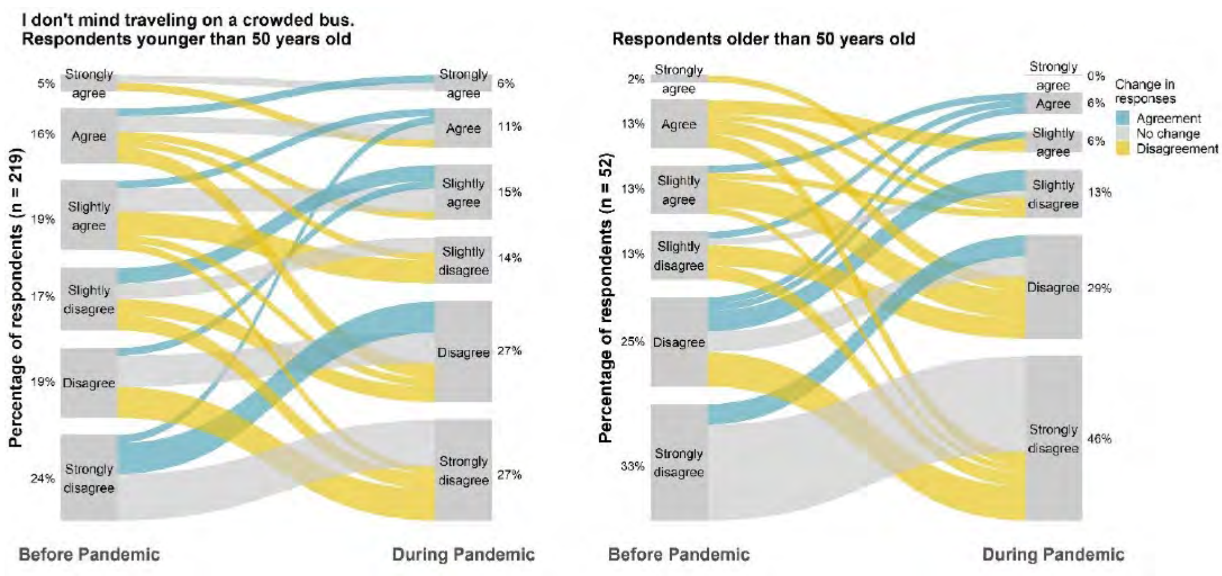


Figure 2: Mapping of individual responses before the pandemic to same individual's response during the pandemic for the statement "I don't mind traveling on a crowded bus".

Source: Parastoo Jabbari and Don MacKenzie, "Ride Sharing Attitudes Before and During the COVID-19 Pandemic in the United States," Transport Findings, November 26, 2020, https://doi.org/10.32866/001c.17991

Figure 43 compares the survey responses from a random U.S.-wide sample of 277 travelers questioned in 2019 and then again in May 2020, when the pandemic was underway, about willingness to travel on a crowded bus. The dominance of the gold bars moving downward in comparison to the blue bars moving upward show the attitude shift toward wanting to avoid crowded transit that occurred based on general understanding of how infection spreads influenced by public health guidance. This attitude shift aligns with the drop in transit ridership seen in the pandemic as described previously.

While the public transit industry is constantly seeking evidence that riding transit is not as risky an environment for becoming COVID-19 infected as the public's concern and public health guidance would suggest, a pre-pandemic study had revealed that sharing the air in any closed space—for example, a vehicle interior—raises the probability of becoming infected from airborne viri.[104, 105]

Because coronavirus infection is able to spread from person to person through shared breathing at commonly close interpersonal distances seen on public transit vehicles in normal times, the practice of shared mobility has been constrained in 2020 in response to public health protocols. Vehicle passengers sitting side by side or in closely spaced rows of seats is no longer being facilitated by transit agencies as long as the health emergency is underway.

Guidance from the U.S. Government Occupational Health and Safety Administration (OSHA) is to "limit the number of passengers drivers can transport at a single time, and install plexiglass partitions between driver and passenger compartments where possible."[106]

CDC guidance for passenger in ride share vehicles illustrates the social distancing requirement:[107]

- Limit the number of passengers in the vehicle to only those necessary.
- Avoid shared rides where multiple passengers are picked up who are not in the same household.
- Sit as far as possible from the driver, such as in the rear seat diagonally across from the driver. In larger vehicles, such as vans and buses, sit in the back seat so you can remain at least six feet away from the driver.
- Improve ventilation
- Ask the driver to improve the ventilation in the vehicle if possible—for example, by opening the windows or setting the air ventilation/air conditioning on non-recirculation mode.

Plexiglass barriers between the driver and the vehicle occupants are being used in a growing number of small ride service vehicles in order to slow the spread of infectious disease on transit. For example, the ride service company Via describes the safety measures for its passenger van micromobility service in one agency as follows: "[r]ider and driver health and safety are a priority, and all vehicles are equipped with plexiglass partitions, capped at three passengers to ensure distancing, and frequently sanitized by the drivers. Masks or face coverings worn over the nose and mouth are required by passengers and drivers."[108]

Additional COVID related infection risk reduction benefits that come with microtransit include:

- A vehicle operator taking action to enforce public health guidance is easier in small vehicle interiors than in large
- Contact tracing compatibility with on-demand service where all passengers are known by name and address
- Vehicle load management is easy with on-demand service by not offering rides that would put too many customers in one vehicle
- Anti-viral passenger cabin air treatments for vehicle interiors more likely successful in small on-demand vehicle interiors than in regular buses.

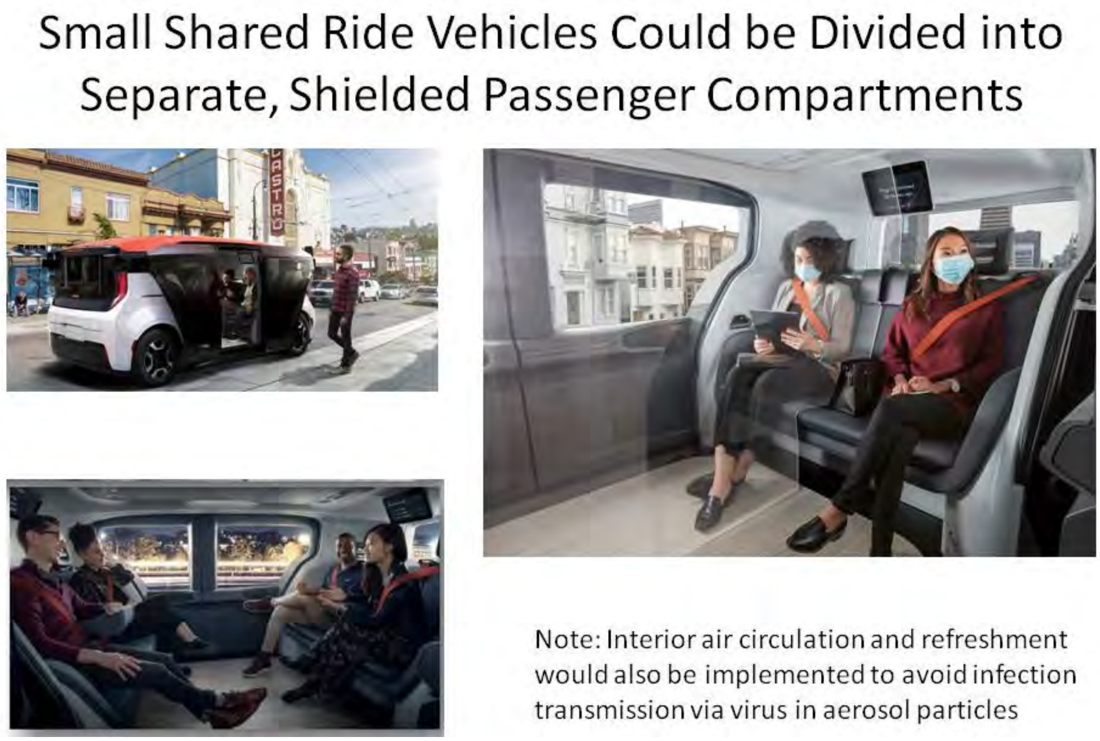
With respect to the last bullet, the air inside of microtransit vehicles can be kept ventilated and then cleaned with a small filter containing ultraviolet light. The science of ultra-violet air cleaning is described by the National Institute of Health.[109] There are examples of products for transit using this technique.[110] The transit agency in Honolulu Hawaii is testing UV air purification.[111]

Another approach is to inject a virus deactivation mist of triethylene glycol, into the air in a controlled manor. This approach is being developed into a product for use in buses and vans by the long established transit equipment vendor Luminator Technology Group, in conjunction with a chemical company. The use of this technique has been approved by the U.S. Environmental Protection Agency in Georgia and Tennessee.[112]

Fast, contactless fare payment with no handling of cash or fare media by the driver is best practice for touch limitation, and is normal practice in modern microtransit implementation for fast boarding and lower driver distraction.

For the future, the design of on-demand shuttle vehicles could configure passenger compartments for isolation of riders not in the same traveling party, using barriers that are easy to envision in prototype shuttle designs like the one from General Motors Cruise division, pictured in Figure 44.

Figure 44. Graphic Renderings of the GM Cruise Origin Automated Taxi



Note: The right hand picture shows the use of a transparent partition to provide some isolation between passengers sitting closely together.
Source of photos: https://getcruise.com

In conclusion, both in the short term and the long term, there are numerous steps that can be taken to make pre-arranged, capacity controlled trips via mobility on-demand in small vehicles as safe in the pandemic as the fixed route experience of walk-up passengers at street side bus stops who board available socially distanced spaces on 40 foot buses.

18. Recommendations for California Transit

From the findings and conclusions of this research, this section provides five recommendations for organizations focused on the success of California public transit agencies.

One specific organization with a statewide emphasis on transit agencies of all sizes that this research points to is the California Department of Transportation (Caltrans) Division of Rail and Mass Transportation (DRMT) within the California State Transportation Agency (CalSTA), a major arm of the State Government.

A second target for our recommendations is the California Transit Association, an industry association closely affiliated with the American Public Transportation Association (APTA). This association has an "emerging mobility" focus area of interest.

A third statewide transit supportive organization is California Association of Coordinated Transportation (CALACT) that could be involved in helping agencies with new on-demand service patterns.

A fourth type of organization, capable of providing implementation assistance to transit agencies would be California's larger Metropolitan Planning Organizations, such as the Bay Area Metropolitan Transportation Commission, Southern California Association of Governments, and San Diego Association of Governments.

All of these organizations are well-versed in the processes of obtaining grant in-aid financial support from the USDOT to implement the following recommendations:

1. Provide advocacy and technical assistance to California transit agencies that keeps on-demand, general purpose microtransit in focus as an option.

Transit agencies in California should be encouraged to maintain a continuous learning and research process for assessing when the service productivity of fixed route, scheduled service boardings fall to a level that the route could reasonably be replaced with on-demand microtransit.

Examples of practice in operational deployments are collected by APTA, trade magazines such as *Mass Transit*, and vendors of microtransit solutions. These examples should be assessed for relevance to California agencies, and curated by one of the transit supportive organizations mentioned above to display consistent and comparable information. The database should then be disseminated via dashboard pages on the internet, on-line and in-person meetings, social media, and both general purpose and professionally specific news media.

2. Develop and implement a transit operations simulation service bureau.

A statewide service bureau should be established to provide transit agencies the ability to create online simulations of their operations that display an overview of markets, operations, and performance metrics. These simulations for specific territories with a common software engine as the backbone, should be kept updated and on standby to show how current services are working, and to display metrics for alternative future service configurations. This capability would allow transit agencies to have an ongoing digital twin of their operations that demonstrates service improvements by allowing depiction of changes in advance. The ability to plan for and visualize the migration of fixed route lines to on-demand service zones, as seen in the example of Figure 34 in Section 12, would be very useful for agencies. Additionally, agencies should maintain a process for assessing when on-demand microtransit should be converted into a fixed route scheduled service with higher capacity, and maintain a stand-by process for justifying and implementing such a conversion when productivity standards demand.

3. Develop and promote best practices in private sector engagement and service procurement.

Procuring microtransit turn-key operations or components of such a system as visualized in a digital twin simulation requires innovative partnerships with the private sector that begin with complex competitive procurements. Sharing of RFPs and processes among agencies is already happening, but assessment of results as procurements occur should be documented, and workable best practices disseminated. Coordinated, cooperative multi-agency procurements should be pursued as well, facilitated by the CalSTA and CALACT associations.

4. Continue and emphasize Fare Payment Integration Work.

As the microtransit mode is added to public transit service options in California, implementation would be smoothed if all transit agencies in the state worked to achieve complete alignment with the existing and active Caltrans Integrated Travel Program, which is striving to develop "Data, payment and tech services that solve the challenges of taking transit today and put every Californian on the same payment standard as a typical debit or credit card."[113] As a starting point, this alignment would take transit well on its way to making microtransit feeder services work with the existing smart card payment system that is in place for customers of the agency's existing buses and trains.

Furthermore, in January 2021, the California Association of Coordinated Transportation (CALACT), a trade association focused on "small, rural, and specialized transportation providers statewide" in California, was awarded a $5.3 million grant for a project titled "Plan, Book, and Pay for Demand-responsive Transit Agencies…" characterized in the proposal as a "Complete Trip deployment pilot project."[114]

The Ride & Ride research team recommends that Cal-ITP and the CALACT Complete Trip deployment pilot projects, work together cooperatively to make on-demand microtransit easier to book and make payment as easy as paying with cash or credit card at a neighborhood convenience store. This is especially important for riders in mobility disadvantaged communities, that is, travelers with disabilities, older adults, low-income individuals, rural residents, veterans, and limited English proficiency travelers, all in the target population cohort for "complete trips" as described in Section 5. As part of this future, unbanked citizens should be able to buy the payment media they need to ride transit from retail locations ranging from super center big box retail locations to corner convenience stores.

5. Monitor the development and effectiveness of COVID safety measures and recommend best practices to transit agencies.

Even as the pandemic winds down in 2021, the public transit industry should be working on ways to make the interior air in multi-passenger vehicles permanently virus-free with ventilation protocols and interior air virus deactivation treatments like filtering, ultra-violet light, and chemical haze.

6. Embrace and seek ways to support appropriate staged deployments of road vehicle automation in the operation of future public transportation services.

This includes maintaining an institutional and continuously updated understanding of the paths going forward for transit automation as described in the previous findings, emphasizing roboshuttles that can work on roads shared with other vehicles.

In summary, the slow recovery of ridership on public transportation in the State of California in the first quarter of 2021 should be used by transit supporting organizations to stimulate new motivation for dramatic changes in service delivery that will generate public interest in climbing aboard.

19. Conclusion

In conclusion, the status of public transit in California in April 2021—mirrored nationally, coming off years of patronage decline, and with a new era underway of responding to what COVID has done to economic patterns and mobility habits—compels planning for dramatic change aimed at performance improvement within the public transit budgets set by elected leadership.

The dire consequences of the pandemic and the need for changes both short and long term were noted in a November 2020 report on the results of a six-month expert panel study led by Susan Shaheen and Stephen Wong, scholars at the University of California Berkeley, Institute of Transportation Studies:

> *Overall, the COVID-19 crisis not only devastated many public transit and shared mobility services, but it exposed underlying issues in how mobility is provided to society. Short-term fixes, while critical, will not solve pervasive transportation issues related to access, high-quality service, and social equity. For public transit and shared mobility services to recover in the short- and long-term, they will require a significant focus on policy and planning to ensure future sustainability that meets critical societal goals.*[115]

Another expert panel, the Bay Area MTC Blue Ribbon Transit Recovery Task Force, put a similar problem summary on record in March 2021, quoted in Section 2.

In line with the assessments of these two expert panels' and with help from regional and statewide transit supportive organizations, California transit agencies should continue to consider, plan, and implement mobility on demand services combining general purpose trips as well as the special trips for ADA qualified passengers and non-emergency health trips. Successful implementation requires exploiting technology applications to dispatch appropriately sized and equipped vehicles to cover an expanding number of locations where mobility disadvantaged populations reside, and then transport multi-passenger loads while keeping waiting times attractive.

Transit agencies are likely to discover that in some cases, fixed route transit corridors suffering high costs not justified by the realized level of passenger demand and ridership could be replaced by on-demand microtransit zones that provide better service and expanded geographic coverage for the same or lower cost. Periods during the week of low public transit demand in any environment can be filled in with private taxi and e-hail services supported by subsidies applied trip by trip, within a capped subsidy budget.

Ridership recovery from the depressed levels of 2021 can be targeted to provide complete origin-to-destination trips for presently underserved populations and neighborhoods by introducing new, high quality, on-demand, point-to-point services that are well promoted, marketed, and priced. Multi-agency bulk procurements from a growing industry of private providers have the potential to yield economies of scale that can help keep costs manageable within constrained budgets. Exploiting the opportunity to build back ridership through innovative services is less risky than doubling down on existing service patterns that were exhibiting falling ridership before the pandemic began.

Computer based simulations are worth exploring as a key planning and monitoring process in any transit effort to expand geographic coverage efficiently and target support for social equity for mobility disadvantaged populations. Microtransit feeder services to mainline fixed route rail and high usage bus trunk lines should be targeted at neighborhoods most in need of subsidized mobility service as determined from available data.

In the long-run, looking ahead by a decade, the most likely scenario of transit agencies achieving the ridership recovery desired by agency leadership, with acceptable costs per traveler, would include driverless, shared use, on-demand, small vehicles with virus-free interior air. These vehicles would be computer-algorithm-dispatched, with non-driving human attendants—not compensated as skilled vehicle operators—to assist passengers. This kind of taxi-like service would seamlessly feed the fixed route rail, and high-performance bus lines that carry sufficient numbers of customers to survive financially in the post-pandemic period.

Endnotes

[1] John Niles and J.M. Pogodzinski, "TOD and Park-and-Ride: Which is Appropriate Where?" Mineta Transportation Institute, 202, https://doi.org/10.31979/mti.2021.1820

[2] Apple Maps Mobility Trend Reports, https://covid19.apple.com/mobility

[3] Adam Burger, VTA staff, Personal communication to the authors, March 23, 2021.

[4] https://www.cdc.gov/coronavirus/2019-ncov/more/scientific-brief-sars-cov-2.html

[5] https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/social-distancing.html

[6] https://www.osha.gov/Publications/OSHA4021.pdf

[7] Ryan Broderick "Uber And Lyft Have Suspended Uber Pool And Shared Rides Due To The Coronavirus," March 17, 2020, https://www.buzzfeednews.com/article/ryanhatesthis/uber-suspends-uber-pool-due-to-coronavirus

[8] Parastoo Jabbari and Don MacKenzie, "Ride Sharing Attitudes Before and During the COVID-19 Pandemic in the United States," https://doi.org/10.32866/001c.17991

[9] Matt Robinson, "Post-pandemic plunge projected for TransLink ridership and revenue," Vancouver Sun, front page, April 5, 2021, https://vancouversun.com/newBis/locballi-noewgs/rpaostp-phanyde mic-plunge-projected-for-translink-ridership-and-revenue

[10] Metropolitan Transportation Commission, Blue Ribbon Transit Recovery Task Force, Revised Final Draft Problem Statement, March 22, 2021, http://mtc.legistar.com/gateway.aspx?M=F&ID=0fa6e06b-9858-4576-a042-3d77d93cd193.pdf

[11] The San Francisco Combined Statistical Area (CSA) covers 14 counties, ranging from Santa Rosa to Hollister and reflects commuting patterns into San Francisco, Oakland, and San José.

[12] Hernan Galperin, et al, "CETF-USC Statewide Broadband Adoption Survey," April 2021, https://pressroom.usc.edu/pandemic-pushes-california-into-new-age-of-telehealth-and-telecommuting/

[13] California State Transportation Agency, "CAPTI: Climate Action Plan for Transportation Infrastructure," March 2021, https://calsta.ca.gov/-/media/calsta-media/documents/capti-2021-calsta.pdf

[14] https://afdc.energy.gov/laws/

[15] https://caltransit.org/news-publications/publications/transit-california/transit-california-archives/2020-editions/april/essential-service/

[16] Luyu Liu, Harvey J. Miller, and Jonathan Scheff, "The impacts of COVID-19 pandemic on public transit demand in the United States," *PLoS ONE* 15, no. 11 (2020): e0242476, https://doi.org/10.1371/journal.pone.0242476

[17] Adam Burger, VTA staff, Personal communication to authors, March 23, 2021

[18] Transit Center, https://transitcenter.org/mapping-route-by-route-whos-riding-transit-during-the-pandemic/

[19] Madeleine Parker, Meiqing Li, Mohamed Amine Bouzaghrane, Hassan Obeid, Drake Hayes, Karen Trapenberg Frick, Daniel Rodriguez, Joan Walker, Raja Sengupta, and Daniel Chatman. "Transit in the era of COVID-19: Public transit policies and travel behavior in the COVID-19 recovery period," Presentation at International E-conference on Pandemics and Transport Policy for a Harmonized World, December 11, 2020, https://home.hiroshima-u.ac.jp/~zjy/international-e-conference-on-pandemics-transport-policy/

[20] Saar Golde and Andrei Greenawalt, "New Data Suggests On-Demand Transit is Essential for Equity," *Meeting of the Minds* (blog), August 2020, https://meetingoftheminds.org/new-data-suggests-on-demand-transit-is-essential-for-equity-34051

[21] https://www.cdc.gov/coronavirus/2019-ncov/daily-life-coping/using-transportation.html

[22] That is, hours when the vehicle is available to carry passengers.

[23] https://www.transit.dot.gov/ntd/national-transit-database-ntd-glossary

[24] National Highway Traffic Safety Administration, "Older Population | 2015 Data," Traffic Safety Facts, February 2017, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812372.

[25] Reid Ewing, "Transportation & Land Use Innovations: When You Can't Pave Your Way 8 Out of Congestion," American Planning Association, Chicago, 1997

[26] John S. Niles and J.M. Pogodzinski, "Bus Transit Operational Efficiency Resulting from Passenger Boardings at Park-and-Ride Facilities," Mineta Transportation Institute, https://scholarworks.sjsu.edu/mti_publications/220/.

[27] https://its.dot.gov/its4us/htm/overview.htm

[28] https://its.dot.gov/its4us/htm/overview.htm

[29] Bern Grush and John Niles, *The End of Driving: Transportation Systems and Public Policy Planning for Autonomous Vehicles*, Elsevier, 2018, Chapter 5.

[30] Joanna Moody, "Valuing private car ownership and use in the United States," MIT Energy Initiative Webinar, November 10, 2020, http://www.mit.edu/~jcmoody/projects/carpride.shtml

[31] Michael Burrows, Charlynn Burd, Adam Smith, Wan He, and Brian McKenzie U.S. Census Bureau, American Community Survey Reports, ACS-45,The Commuting Patterns of Older Workers: 2013-2017, U.S. Government Printing Office, Washington, DC, November 2020 https://www.census.gov/content/dam/Census/library/publications/2020/acs/acs-45.pdf

[32] International Energy Agency, "Global EV Outlook 2020," https://www.iea.org/reports/global-ev-outlook-2020

[33] California Office of the Governor, "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change," September 23, 2020, https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/

[34] Insurance Institute for Highway Safety, "Real-world benefits of crash avoidance technologies," December 2020, https://www.iihs.org/media/259e5bbd-f859-42a7-bd54-3888f7a2d3ef/shuYZQ/Topics/ADVANCED%20DRIVER%20ASSISTANCE/IIHS-real-world-CA-benefits.pdf

[35] Marlon Boarnet and Susan Handy, "A Framework for Projecting the Potential Statewide Vehicle Miles Traveled (VMT) Reduction from State-Level Strategies in California," White Paper from the National Center for Sustainable Transportation, March 2017, https://ntlrepository.blob.core.windows.net/lib/61000/61900/61924/State-Level-VMT-Strategies-White-Paper_FINAL-03.2017.pdf

[36] University of Minnesota Accessibility Observatory, "Access Across America," http://access.umn.edu/publications/america/

[37] M. McGurrin, "A Brief Note on Modal Access across America," 2017, https://www.mcgurrin.com/2017/02/13/a-brief-note-on-modal-access-across-america/.

[38] University of Minnesota, "Park-and-ride transit gives suburban commuters higher access to jobs," *Phys.Org* (blog), May 22, 2019, https://phys.org/news/2019-05-park-and-ridetransit-suburban-commuters-higher.html.

[39] Eno Center for Transportation, "UpRouted: Exploring Microtransit in the United States," January 08, 2018. https://www.enotrans.org/wp-content/uploads/2018/01/UpRouted-18.pdf

[40] Russ Hancock, Transportation Panel A: The Manzanita Talks video, https://vimeo.com/399006182

[41] Zara Stone, "Inside a Secretive $250 Million Private Transit System Just for Techies," February 24, 2020. https://onezero.medium.com/only-the-elite -have-nice-commutes-in-silicon-valley-8b2761863925

[42] Giuseppe Inturri, Michela Le Pira, Nadia Giuffrida, Matteo Ignaccolo, Alessandro Pluchino, Andrea Rapisarda, and Riccardo D'Angelo, "Multi-agent simulation for planning and designing new shared mobility services," *Research in Transportation Economics,* 73 (2019): 34–44, https://doi.org/10.1016/j.retrec.2018.11.009

[43] Via web, https://ridewithvia.com/resources/articles/what-is-microtransit/

[44] Joseph Schwieterman, Mallory Livingston, and Stijn Van Der Slot, "Partners in Transit: A Review of Partnerships between Transportation Network Companies and Public Agencies in the United States," August 2018, https://www.researchgate.net/publication/328575814_Partners_in_Transit_A_Review_of_Partnerships_between_Transportation_Network_Companies_and_Public_Agencies_in_the_United_States; Mallory Livingston and Joe Schwieterman. "21 Key Takeaways from Partnerships between Public Transit Providers &

Transportation Network Companies in the United States,"Chaddick Institute Policy Series, April 14,2020, https://www.researchgate.net/publication/342109638_21_Key_Takeaways_from_Partnerships_between_Public_Transit_Providers_Transportation_Network_Companies_in_the_United_States

[45] R.R. Clewlow and G.S. Mishra, "Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States," UC Davis: Institute of Transportation Studies. 2017, https://escholarship.org/uc/item/82w2z91j

[46] Emma Lucken, Karen Trapenberg Frick, and Susan A. Shaheen, "Three Ps in a MOD: Role for mobility on demand (MOD) public-private partnerships in public transit provision," *Research in Transportation Business & Management*, 32, (2019): 100433, https://doi.org/10.1016/j.rtbm.2020.100433

[47] Santa Clara Valley Transportation Authority, "Dynamic Transit Program -FLEX Pilot Project Update," Board Memorandum to Santa Clara Valley Transportation Authority Transit Planning & Operations Committee Through General Manager, Nuria I. Fernandez From Director of Planning and Program Development John Ristow, August 17, 2016, http://vtaorgcontent.s3-us-west-1.amazonaws.com/Site_Content/tpo_090116_packet.pdf

[48] https://www.thesanjoseblog.com/2016/01/vta-flex-program.html

[49] Leslie Gray, "The Silicon Valley Agency Launching its Own Microtransit Service," *Shared Use Mobility Center* (blog), January 10, 2016, https://sharedusemobilitycenter.org/the-silicon-valley-agency-launching-its-own-microtransit-service/

[50] Adam Burger, VTA staff, personal communication to authors, March 23, 2021

[51] Marla Westervelt, et al., "UpRouted: Exploring Microtransit in the United States," Eno Center for Transportation, January 2018, 11, https://www.enotrans.org/wp-content/uploads/2018/01/UpRouted-18.pdf?x43122

[52] Kirsten Korosec, "Via is launching an on-demand public transit network in the city of Cupertino," *TechCrunch* (blog), https://techcrunch.com/2019/10/07/via-and-city-of-cupertino-are-launching-an-on-demand-public-transit-network/

[53] Santa Clara Valley Transportation Authority, "Alternative Service Models and Mobility Program," Memorandum for the Board of Directors Capital Planning Committee. August 21, 2020 " http://docplayer.net/192854292-Date-august-21-2020-current-meeting-august-27-2020-board-meeting-board-memorandum.html

[54] Santa Clara Valley Transportation Authority, "Core Connectivity Program, Update [for] Advisory Committees," January 2018, PDF, 39 at http://vtaorgcontent.s3-us-west-1.amazonaws.com/Site_Content/pac_011118_packet.pdf

[55] Santa Clara Valley Transportation Authority, "Core Connectivity Program, Update [for] Advisory Committees," January 2018, PDF, 44 at http://vtaorgcontent.s3-us-west-1.amazonaws.com/Site_Content/pac_011118_packet.pdf

[56] Emma Lucken, Karen Trapenberg Frick, and Susan A. Shaheen, "Three Ps in a MOD: Role for mobility on demand (MOD) public-private partnerships in public transit provision," Research in Transportation Business & Management, 32, (2019): 100433, https://doi.org/10.1016/j.rtbm.2020.100433

[57] Denver RTD, First and Last Mile Strategic Plan, Spring 2019, https://www.rtd-denver.com/sites/default/files/files/2019-07/FLM-Strategic-Plan_06-10-19.pdf

[58] National Academies of Sciences, Engineering, and Medicine. *Microtransit or General Public Demand Response Transit Services: State of the Practice*, (Washington, DC: The National Academies Press), 2019, https://doi.org/10.17226/25414.

[59] U.S. Department of Transportation, "Technology Sharing: Paratransit, State of the Art Overview," March 1981, http://libraryarchives.metro.net/DPGTL/usdot/1981-paratransit-technology-sharing-state-of-the-art-overview-march.pdf

[60] Agreement Between Santa Clara Valley Transportation Authority and Amalgamated Transit Union Division 265, Septembat 9, 2019 through September 8, 2022, 23, https://www.vta.org/sites/default/files/2019-10/ATU%20Contract%202019%20-%202022.pdf

[61] Adam Burger, VTA staff, personal communication to authors, March 23, 2021

[62] Joël Hazan, Nikolaus Lang, Augustin K. Wegscheider, and Benjamin Fassenot, "On-Demand Transit Can Unlock Urban Mobility," Boston Consulting Group, November 07, 2019

[63] City of Cupertino, "City Council Staff Report" June 18, 2019 https://www.cupertino.org/home/showdocument?id=24577

[64] Adam Burger, VTA staff, personal communication to authors, March 23, 2021

[65] https://www.valleyregionaltransit.org/routes/nampa-caldwell-ondemand/

[66] Derek Edwards and Kari Edison Watkins, "Comparing Fixed-Route and Demand-Responsive Feeder Transit Systems in Real-World Settings," *Transportation Research Record: Journal of the Transportation Research Board* 2352, no. 1 (2013):128-135, http://doi.org/10.3141/2352-15

[67] TransitCenter, "Microtransit + Transit," Transit Tools no. 13, November 2019, https://transitcenter.org/wp-content/uploads/2019/11/Microtransit-1-1.pdf

[68] National Academies of Sciences, Engineering, and Medicine, *Microtransit or General Public Demand Response Transit Services: State of the Practice* (The National Academies Press. Washington, DC, 2019), https://doi.org/10.17226/25414.

[69] *Mass Transit*. https://www.masstransitmag.com/alt-mobility/shared-mobility/press-release/21153770/sacramento-regional-transit-sacrt-sacrts-smart-ride-microtransit-service-among-most-success-in-us

[70] Westervelt, et al., "UpRouted: Exploring Microtransit in the United States" Eno Center for Transportation, Washington, DC, 2018

[71] AC Transit, https://www.actransit.org/flex-draft

[72] National Academies of Sciences, Engineering, and Medicine 2021. RedesigningTransit Networks for the New Mobility Future. Washington, DC: The NationalAcademies Press, Table 3, https://doi.org/10.17226/26028.

[73] LA Metro, Procurement Summary, Microtransit Pilot Project, Contract No. PS46292001, http://metro.legistar1.com/metro/attachments/2a26b9e1-5552-40f1-ba31-1bb1d4b0d856.pdf

[74] Ride & Ride research team's environmental scan of California public transit agency representations of their activity on the world wide web of the Internet, March 2021.

[75] Community Transportation Association of America, "Welcome to Transit Planning 4 All" https://transitplanning4all.org/

[76] Morgan Cowick and Daniel Munkel, "Prioritizing Areas for King County Metro Transit's Feeder-to-Fixed Route Flexible Services: A Preliminary Approach for the Systematic Locational Prioritization of Future Services," College of Built Environments -Department of Urban Design and Planning, Evans School for Public Policy and Governance, University of Washington, June 2020, https://kingcounty.gov/~/media/depts/metro/programs-projects/innovative-mobility/pdf/prioritizing-feeder-to-fixed-route-flexible-services-full-report.pdf

[77] National Academies of Sciences, Engineering, and Medicine. *Microtransit or General Public Demand Response Transit Services: State of the Practice* (The National Academies Press, Washington, DC, 2019), https://doi.org/10.17226/25414

[78] Eno Center for Transportation. "UpRouted: Exploring Microtransit in the United States." January 08, 2018.

[79] https://pantonium.com/wp-content/uploads/2021/01/RFP-2020-03-09-On-Demand-Technology.pdf

[80] John Niles, "Full Potential of Future Robotaxis Achievable with Trip-Based Subsidies and Fees Applied to the For-Hire Vehicles of Today," Mineta Transportation Institute, August 2019, https://scholarworks.sjsu.edu/cgi/viewcontent.cgi?article=1274&context=mti_publications

[81] https://rideal.mobi/

[82] State of California Health and Human Services Agency, Department of Health Care Services, "Non-emergency medical and non-medical transportation services, "All-Plan Letter 17-010 (revised), July 17, 2017, https://www.dhcs.ca.gov/formsandpubs/Documents/MMCDAPLsandPolicyLetters/APL2017/APL17-010.pdf

[83]Via, "Integrated Mobility Solution: Golden Empire Transit Case Study," 2021 https://www.dropbox.com/s/oo53lhpuk9b7ma1/Bakersfield-NEMT-paratransit-on-demand%20integration%20case%20study%2C%20Via.pdf

[84] Md Mintu Miah, Farah Naz, Kate (Kyung) Hyun, Stephen P. Mattingly, Courtney Cronley, and Noelle Fields, "Barriers and opportunities for paratransit users to adopt on-demand micro transit," *Research in Transportation Economics*, 84 (2020): 101001, https://doi.org/10.1016/j.retrec.2020.101001

[85] Bay Area Metropolitan Transportation Commission,"Coordinated Public Transit Human Services Transportation Plan," pg. 2, February 2018, https://mtc.ca.gov/sites/default/files/MTC_Coordinated_Plan.pdf

[86] Santa Clara County Social Services Agency, Department of Aging and Adult Services. Senior's Agenda: Annual Report 2019, pg. 19 https://extranet.who.int/agefriendlyworld/wp-content/uploads/2020/02/Seniors-Agenda-Annual-Report-2019.pdf.

[87] Bern Grush and John Niles, *The End of Driving: Transportation Systems and Public Policy Planning for Autonomous Vehicles*, Elsevier, 2018

[88] Grush and Niles, *The End of Driving: Transportation Systems and Public Policy Planning for Autonomous Vehicles*

[89] M.P. Enoch, "How a rapid modal convergence into a universal automated taxi service could be the future for local passenger transport," *Technology Analysis & Strategic Management* 27, no. 8: 910-924. https://doi.org/10.1080/09537325.2015.1024646

[90] The White House, "Fact Sheet: Biden Administration Advances Electric Vehicle Charging Infrastructure," April 22, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-biden-administration-advances-electric-vehicle-charging-infrastructure/

[91] Heather McRea, "Thousands rode Anaheim's free FRAN system in its first year," *Orange County Register*, January 14, 2020, https://www.ocregister.com/2020/01/13/thousands-rode-anahiems-free-fran-system-in-its-first-year/

https://gem.polaris.com/en-us/articles/news/anaheim-debuts-unique-all-electric-microtransit-service/

[92] Melanie Curry, "Fresno County Launches Rural Electric MicroTransit Pilot," Streetsblog California, October 23, 2020, https://cal.streetsblog.org/2020/10/23/fresno-county-launches-rural-electric-microtransit-pilot/

[93] Raphaël Gindrat, "How To Use Data To Get Micro-Transit Right," February 27, 2019, https://www.forbes.com/sites/forbestechcouncil/2019/02/27/how-to-use-data-to-get-micro-transit-right/

[94] Joseph Y. J. Chow, Srushti Rath, Gyugeun Yoon, Patrick Scalise, and Sara Alanis Saenz, "Spectrum of Public Transit Operations: From Fixed Route to Microtransit," C2SMART University Transportation Center, March 2020, https://c2smart.engineering.nyu.edu/wp-content/uploads/2020/04/Chow-FTA-Report-NY-2019-069-01-00.pdf

[95] Caroline Rodier, Andrea Broaddus, Miguel Jaller, Jeffery Song, Joschka Bischoff and Yunwan Zhang, "Cost-Benefit Analysis of Novel Transit Access Modes: A Case Study in the San Francisco Bay Area," Mineta Transportation Institute, Report 20–46, November 2020, https://transweb.sjsu.edu/sites/default/files/1816-Rodier-Cost-Benefit-Analysis-Novel-Transit-Access-Modes.pdf

[96] Luis Martinez, Olga Petrik, and Nicolas Wagner, "Shared Mobility Simulations for Lyon," International Transport Forum, OECD, 2020, https://www.itf-oecd.org/sites/default/files/docs/shared-mobility-simulations-lyon.pdf

[97] Jacek Pawlak, Giovanni Circella, Hani S. Mahmassani, and Patricia L. Mokhtarian, "Information And Communication Technologies(ICT), Activity Decisions, and Travel Choices: 20 years into the Second Millennium and where do we go next?" TRB Centennial Papers, November 2020, http://onlinepubs.trb.org/onlinepubs/centennial/papers/ADB20-Final.pdf

[98] Nadia Giuffrida, Michela Le Pira, Giuseppe Inturri, and Matteo Ignaccolo, "Addressing the public transport ridership/coverage dilemma in small cities: A spatial approach," *Case Studies on Transport Policy*, In press, 2021

[99] Streetlight Data, "Bus and Rail Metrics Methodology," February 2021 https://learn.streetlightdata.com/bus-and-rail-methodology

[100] Via, Inc., "Via Arlington expands citywide starting January 19," Press release, January 14, 2021, https://ridewithvia.com/news/via-arlington-expands-citywide-starting-january-19/

[101] Argonne National Laboratory, "Argonne and the Chicago Transit Authority dissect how transit changes will impact mobility," January 13, 2021, https://www.anl.gov/es/article/argonne-and-the-chicago-transit-authority-dissect-how-transit-changes-will-impact-mobility, January 13, 2021

[102] Nicholas A. Christakis, *Apollo's Arrow The Profound and Enduring Impact of Coronavirus on the Way We Live,* (Little Brown, New York, 2020).

[103] Matt Robinson, "Post-pandemic plunge projected for TransLink ridership and revenue," *Vancouver Sun*, April 5, 2021, https://vancouversun.com/news/local-news/post-pandemic-plunge-projected-for-translink-ridership-and-revenue

[104] Sam Schwartz, "Public Transit and COVID-19 Pandemic: Global Research and Best Practices," independent research paper commissioned by American Public Transportation Association, September 2020, https://www.apta.com/wp-content/uploads/APTA_Covid_Best_Practices_09.29.2020.pdf

[105] Lara Goscé and Anders Johansson, "Analysing the link between public transport use and airborne transmission: mobility and contagion in the London underground" *Environmental Health* 17, no. 84, (2018), https://doi.org/10.1186/s12940-018-0427-5

[106] https://www.osha.gov/Publications/OSHA4021.pdf

[107] https://www.cdc.gov/coronavirus/2019-ncov/daily-life-coping/using-transportation.html#RideShare

[108] https://ridewithvia.com/news/city-of-salem-launches-the-salem-skipper-on-demand-transit-for-residents-commuters/

[109] https://pubmed.ncbi.nlm.nih.gov/32673522/

[110] https://www.valeo-thermalbus.com/eu_en/Innovation/UV-air-purification

[111] https://www.masstransitmag.com/technology/press-release/21164002/city-and-county-of-honolulu-department-of-transportation-services-honolulu-testing-air-purification-systems-and-uv-light-treatment-on-transit-vehicles

[112] Luminator Technology Group, "Air treatment solution for public transit approved by EPA to provide continuous protection against COVID-19: Luminator Technology Group's Renew™ Air Treatment System utilizes Grignard Pure™ to kill more than 98 percent of SARS-CoV-2 airborne virus particles," *Mass Transit trade magazine*, January 20, 2021, https://www.masstransitmag.com/bus/vehicles/hvac/press-release/21206619/air-treatment-solution-for-public-transit-approved-by-epa-to-provide-continuous-protection-against-covid19

[113] The California Integrated Travel Project (Cal-ITP), home page, https://dot.ca.gov/cal-itp

[114] U.S. Department of Transportation, "About Complete Trip - ITS4US Deployment Program," https://www.its.dot.gov/its4us/index.htm#CALACT

[115] Susan Shaheen and Adam Wong, "Future of Public Transit and Shared Mobility: Scenario Planning for COVID-19 Recovery," University of California Institute of Transportation Studies, November 2020, https://doi.org/10.7922/G2NC5ZGR

Bibliography

Bay Area Metropolitan Transportation Commission, "Coordinated Public Transit Human Services Transportation Plan," February 2018, https://mtc.ca.gov/sites/default/files/MTC_Coordinated_Plan.pdf

Boarnet, Marlon and Susan Handy. "A Framework for Projecting the Potential Statewide Vehicle Miles Traveled (VMT) Reduction from State-Level Strategies in California." White Paper from the National Center for Sustainable Transportation, March 2017, https://ntlrepository.blob.core.windows.net/lib/61000/61900/61924/State-Level-VMT-Strategies-White-Paper_FINAL-03.2017.pdf

Burrows, Michael, Charlynn Burd, Adam Smith, Wan He, and Brian McKenzie. U.S. Census Bureau, American Community Survey Reports, ACS-45, The Commuting Patterns of Older Workers: 2013-2017,U.S. Government Printing Office, Washington, DC, November 2020 https://www.census.gov/content/dam/Census/library/publications/2020/acs/acs-45.pdf

California Office of the Governor. "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change," September 23, 2020, https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/

California, State of, Health and Human Services Agency, Department of Health Care Services. "Non-emergency medical and non-medical transportation services. "All-Plan Letter 17-010 (revised), July 17, 2017, https://www.dhcs.ca.gov/formsandpubs/Documents/MMCDAPLsandPolicyLetters/APL2017/APL17-010.pdf

Chow, Joseph Y. J., Srushti Rath, Gyugeun Yoon, Patrick Scalise, and Sara Alanis Saenz. "Spectrum of Public Transit Operations: From Fixed Route to Microtransit," C2SMART University Transportation Center. March 2020. https://c2smart.engineering.nyu.edu/wp-content/uploads/2020/04/Chow-FTA-Report-NY-2019-069-01-00.pdf

Clewlow, R.R., and G.S. Mishra. "Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States." UC Davis: Institute of Transportation Studies. 2017. https://escholarship.org/uc/item/82w2z91j

Community Transportation Association of America. "Welcome to Transit Planning 4 All." https://transitplanning4all.org/

Cowick, Morgan and Daniel Munkel, "Prioritizing Areas for King County Metro Transit's Feeder-to-Fixed Route Flexible Services: A Preliminary Approach for the Systematic Locational Prioritization of Future Services," College of Built Environments -Department of Urban Design and Planning, Evans School for Public Policy and Governance, University of Washington, June 2020, https://kingcounty.gov/~/media/depts/metro/programs-projects/innovative-mobility/pdf/prioritizing-feeder-to-fixed-route-flexible-services-full-report.pdf

Cupertino, City of. "City Council Staff Report." June 18, 2019. https://www.cupertino.org/home/showdocument?id=24577

Eno Center for Transportation. "UpRouted: Exploring Microtransit in the United States." January 08, 2018. https://www.enotrans.org/wp-content/uploads/2018/01/UpRouted-18.pdf

Enoch, M.P. "How a rapid modal convergence into a universal automated taxi service could be the future for local passenger transport." *Technology Analysis & Strategic Management* 27 no.8: 910-924. https://doi.org/10.1080/09537325.2015.1024646

Ewing, Reid. "Transportation & Land Use Innovations: When You Can't Pave Your Way 8 Out of Congestion."American Planning Association. Chicago, 1997.

Gindrat, Raphaël. "How To Use Data To Get Micro-Transit Right." February 27, 2019. https://www.forbes.com/sites/forbestechcouncil/2019/02/27/how-to-use-data-to-get-micro-transit-right/

Giuffrida, Nadia, Michela Le Pira, Giuseppe Inturri, and Matteo Ignaccolo. "Addressing the public transport ridership/coverage dilemma in small cities: A spatial approach, Case Studies on Transport Policy." In press, 2021.

Golde, Saar and Andrei Greenawalt. "New Data Suggests On-Demand Transit is Essential for Equity." *Meeting of the Minds* (blog). August 2020. https://meetingoftheminds.org/new-data-suggests-on-demand-transit-is-essential-for-equity-34051

Goscé, Lara and Anders Johansson. "Analysing the link between public transport use and airborne transmission: mobility and contagion in the London underground." *Environmental Health* 17, no. 84 (2018). https://doi.org/10.1186/s12940-018-0427-5

Gray, Leslie. "The Silicon Valley Agency Launching its Own Microtransit Service." *Shared Use Mobility Center* (blog). January 10, 2016. https://sharedusemobilitycenter.org/the-silicon-valley-agency-launching-its-own-microtransit-service/

Grush, Bern and John Niles. The End of Driving: Transportation Systems and Public Policy Planning for Autonomous Vehicles. (Elsevier, 2018). Chapter 5.

Hancock, Russ. Transportation Panel A: The Manzanita Talks video. https://vimeo.com/399006182

Hazan, Joël, Nikolaus Lang, Augustin K. Wegscheider, and Benjamin Fassenot. "On-Demand Transit Can Unlock Urban Mobility," Boston Consulting Group, November 07, 2019.

Insurance Institute for Highway Safety. "Real-world benefits of crash avoidance technologies." December 2020. https://www.iihs.org/media/259e5bbd-f859-42a7-bd54-3888f7a2d3ef/shuYZQ/Topics/ADVANCED%20DRIVER%20ASSISTANCE/IIHS-real-world-CA-benefits.pdf

International Energy Agency. "Global EV Outlook 2020." https://www.iea.org/reports/global-ev-outlook-2020

Inturri, Giuseppe, Michela Le Pira, Nadia Giuffrida, Matteo Ignaccolo, Alessandro Pluchino, Andrea Rapisarda, and Riccardo D'Angelo. "Multi-agent simulation for planning and designing new shared mobility services." *Research in Transportation Economics* 73 (2019): 34–44. https://doi.org/10.1016/j.retrec.2018.11.009

Jabbari, Parastoo and Don MacKenzie. "Ride Sharing Attitudes Before and During the COVID-19 Pandemic in the United States." Transport Findings. November 26, 2020. https://doi.org/10.32866/001c.17991

Liu, Luyu, Harvey J. Miller, and Jonathan Scheff. "The impacts of COVID-19 pandemic on public transit demand in the United States." *PLoS ONE* 15 no. 11 (2020): e0242476. https://doi.org/10.1371/journal.pone.0242476

Livingston, Mallory and Joe Schwieterman. "21 Key Takeaways from Partnerships between Public Transit Providers & Transportation Network Companies in the United States." Chaddick Institute Policy Series. April 14, 2020. https://www.researchgate.net/publication/342109638_21_Key_Takeaways_from_Partnerships_between_Public_Transit_Providers_Transportation_Network_Companies_in_the_United_States

Los Angeles County Metro. Procurement Summary, Microtransit Pilot Project,.Contract No. PS46292001. http://metro.legistar1.com/metro/attachments/2a26b9e1-5552-40f1-ba31-1bb1d4b0d856.pdf

Lucken, Emma, Karen Trapenberg Frick, and Susan A. Shaheen. "Three Ps in a MOD:" Role for mobility on demand (MOD) public-private partnerships in public transit provision." *Research in Transportation Business & Management* 32 (2019): 100433. https://doi.org/10.1016/j.rtbm.2020.100433

Luminator Technology Group. "Air treatment solution for public transit approved by EPA to provide continuous protection against COVID-19." *Mass Transit* (2021). https://www.masstransitmag.com/bus/vehicles/hvac/press-release/21206619/air-treatment-solution-for-public-transit-approved-by-epa-to-provide-continuous-protection-against-covid19

Martinez, Luis, Olga Petrik, and Nicolas Wagner. "Shared Mobility Simulations for Lyon." International Transport Forum, OECD. https://www.itf-oecd.org/sites/default/files/docs/shared-mobility-simulations-lyon.pdf

Mass Transit Magazine. https://www.masstransitmag.com/alt-mobility/shared-mobility/press-release/21153770/sacramento-regional-transit-sacrt-sacrts-smart-ride-microtransit-service-among-most-success-in-us

McGurrin, M. "A Brief Note on Modal Access across America." 2017. https://www.mcgurrin.com/2017/02/13/a-brief-note-on-modal-access-across-america/.

Miah, Md Mintu, Farah Naz, Kate (Kyung) Hyun, Stephen P. Mattingly, Courtney Cronley, and Noelle Fields. "Barriers and opportunities for paratransit users to adopt on-demand micro transit." *Research in Transportation Economics* 84 (2020): 101001. https://doi.org/10.1016/j.retrec.2020.101001

Moody, Joanna. "Valuing private car ownership and use in the United States." MIT Energy Initiative Webinar. November 10, 2020. http://www.mit.edu/~jcmoody/projects/carpride.shtml

National Academies of Sciences, Engineering, and Medicine. *Microtransit or General Public Demand Response Transit Services: State of the Practice*. (The National Academies Press. Washington, DC, 2019). https://doi.org/10.17226/25414.

National Highway Traffic Safety Administration. "Older Population | 2015 Data." Traffic Safety Facts. February 2017. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812372.

Niles, John and J.M. Pogodzinski. "TOD and Park-and-Ride: Which is Appropriate Where? Mineta Transportation Institute. 202. https://doi.org/10.31979/mti.2021.1820

Niles, John S. and J.M. Pogodzinski. "Bus Transit Operational Efficiency Resulting from Passenger Boardings at Park-and-Ride Facilities." Mineta Transportation Institute. 2018, https://scholarworks.sjsu.edu/mti_publications/220/

Niles, John. "Full Potential of Future Robotaxis Achievable with Trip-Based Subsidies and Fees Applied to the For-Hire Vehicles of Today." Mineta Transportation Institute. August 2019. https://scholarworks.sjsu.edu/cgi/viewcontent.cgi?article=1274&context=mti_publications

Parker, Madeleine, Meiqing Li, Mohamed Amine Bouzaghrane, Hassan Obeid, Drake Hayes, Karen Trapenberg Frick, Daniel Rodriguez, Joan Walker, Raja Sengupta, and Daniel Chatman. "Transit in the era of COVID-19: Public transit policies and travel behavior in the COVID-19 recovery period." Presentation at International E-conference on Pandemics and Transport Policy for a Harmonized World. December 11, 2020. https://home.hiroshima-u.ac.jp/~zjy/international-e-conference-on-pandemics-transport-policy/

Pawlak, Jacek, Giovanni Circella, Hani S. Mahmassani, and Patricia L. Mokhtarian. "Information And Communication Technologies(ICT), Activity Decisions, and Travel Choices: 20 years into the Second Millennium and where do we go next?" TRB Centennial Papers. November 2020. http://onlinepubs.trb.org/onlinepubs/centennial/papers/ADB20-Final.pdf

Polzin, Steven and Tony Choi. "COVID-19's Effects on The Future of Transportation." Office of the Assistant Secretary for Research and Technology. January 14, 2021. https://rosap.ntl.bts.gov/view/dot/54292

Rodier, Caroline, Andrea Broaddus, Miguel Jaller, Jeffery Song, Joschka Bischoff, Yunwan Zhang. "Cost-Benefit Analysis of Novel Transit Access Modes: A Case Study in the San Francisco Bay Area." Mineta Transportation Institute. Report 20–46, November 2020. https://transweb.sjsu.edu/sites/default/files/1816-Rodier-Cost-Benefit-Analysis-Novel-Transit-Access-Modes.pdf

Santa Clara Valley Transportation Authority. "Dynamic Transit Program -FLEX Pilot Project Update." Board Memorandum to Santa Clara Valley Transportation Authority Transit Planning & Operations Committee Through General Manager, Nuria I. Fernandez From Director of Planning and Program Development John Ristow. August 17, 2016. http://vtaorgcontent.s3-us-west-1.amazonaws.com/Site_Content/tpo_090116_packet.pdf

Santa Clara Valley Transportation Authority. "Alternative Service Models and Mobility Program." Memorandum for the Board of Directors Capital Planning Committee. August 21, 2020.

Santa Clara Valley Transportation Authority. "Core Connectivity Program, Update [for] Advisory Committees." January 2018, 39. http://vtaorgcontent.s3-us-west-1.amazonaws.com/Site_Content/pac_011118_packet.pdf

Schwartz, Sam. "Public Transit and COVID-19 Pandemic: Global Research and Best Practices." independent research paper commissioned by American Public Transportation Association. September 2020. https://www.apta.com/wp-content/uploads/APTA_Covid_Best_Practices_09.29.2020.pd

Schwieterman, Joseph, Mallory Livingston, and Stijn Van Der Slot. "Partners in Transit: A Review of Partnerships between Transportation Network Companies and Public Agencies in the United States." August 2018. https://www.researchgate.net/publication/328575814_Partners_in_Transit_A_Review_of_Partnerships_between_Transportation_Network_Companies_and_Public_Agencies_in_the_United_States;

Shaheen, Susan and Adam Wong. "Future of Public Transit and Shared Mobility: Scenario Planning for COVID-19 Recovery." University of California Institute of Transportation Studies. November 2020. https://doi.org/10.7922/G2NC5ZGR

Shaheen, Susan, Adam Cohen, and Ismail Zohdy. "Report on Shared Mobility: Current Practices and Guiding Principles." USDOT, Federal Highway Administration. March 2016. https://ops.fhwa.dot.gov/publications/fhwahop16022/fhwahop16022.pdf

Soriano, Janice. "VTA Average Daily Ridership by Stop/Station." Tableau map. https://public.tableau.com/profile/janice.soriano#!/vizhome/SystemwideRidershipbyStop/Dashboard1

Stone, Zara. "Inside a Secretive $250 Million Private Transit System Just for Techies." February 24, 2020. https://onezero.medium.com/only-the-elite-have-nice-commutes-in-silicon-valley-8b2761863925

Streetlight Data. "Bus and Rail Metrics Methodology." February 2021. https://learn.streetlightdata.com/bus-and-rail-methodology

TransitCenter. "Mapping Route-By-Route Who's Riding Transit During the Pandemic." July 15, 2020. https://transitcenter.org/mapping-route-by-route-whos-riding-transit-during-the-pandemic/

TransitCenter. "Microtransit + Transit." Transit Tools no. 13. November 2019. https://transitcenter.org/wp-content/uploads/2019/11/Microtransit-1-1.pdf

U.S. Department of Transportation. "Technology Sharing: Paratransit, State of the Art Overview." March 1981. http://libraryarchives.metro.net/DPGTL/usdot/1981-paratransit-technology-sharing-state-of-the-art-overview-march.pdf

University of Minnesota Accessibility Observatory. "Access Across America." http://access.umn.edu/publications/america/

University of Minnesota. "Park-and-ride transit gives suburban commuters higher access to jobs." *Phys.Org* (blog). May 22, 2019. https://phys.org/news/2019-05-park-and-ridetransit-suburban-commuters-higher.html.

Via, Inc. "Via Arlington expands citywide starting January 19." Press release. January 14, 2021. https://ridewithvia.com/news/via-arlington-expands-citywide-starting-january-19/

Westervelt, M., et al. "UpRouted: Exploring Microtransit in the United States." Eno Center for Transportation. Washington, DC, 2018. https://www.enotrans.org/wp-content/uploads/2018/01/UpRouted-18.pdf?x43122

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