CalShuttle - The Future of Bay Area Transit

Waymo 6th-generation robotaxi - based on a body by China-based Geely/Zeekr
(Image courtesy of Waymo - https://waymo.com/blog/2021/12/expanding-our-waymo-one-fleet-with)

GM Cruise Origin - One of many autonomous EV shuttles in development.
(Image Courtesy of Cruise LLC - https://www.getcruise.com/technology)

Amazon-owned Zoox Robotaxi - Another autonomous EV shuttle in development.
(Image courtesy of Zoox - https://zoox.com/vehicle/)

Presto driverless shuttle beginning operation at Bishop Ranch business park in spring 2023.
(Image courtesy of Contra Costa Transit Authority -
https://patch.com/california/sanramon/bay-areas-first-autonomous-shuttles-debut-bishop-ranch)

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1 2033: Your Neighborhood is your Transit Station

Mark steps from the curb into shuttle 4192 on Keesling Avenue in the Willow Glen neighborhood of San Jose. He waves to Sharon and George already on the shuttle. He puts on his seat belt. The shuttle silently drives two blocks to Phantom Avenue, where Julie enters and sits down. Everyone nods to Julie - they often see each other on this shuttle excursion.

Usually Julie is the last pickup. But not today. This shuttle drives around the block to Norman Avenue and picks up Greg. Introductions happen all around. Greg is new to Willow Glen, and this is his first CalShuttle shuttle ride.

The shuttle continues down Norman to Hamilton, merges without stopping with other shuttles traveling west, and onto 17, towards 280, 85, and exits 101 at Shoreline.

During the ride, Sharon and George seem to be already "at work" on their laptops, Julie is dozing, and Greg is busy with on his phone.

Usually Mark would have his attention captured by his laptop in preparation for his day, but not today. Today he is recalling how commuting has changed with CalShuttle.

Mark's overall commute time is a little less than it used to be, and much more relaxing and productive. The coordinated shuttle transit makes for a faster commute and had more than made up for the additional time for the short wait near home and picking up and dropping off passengers. And there are no intermediate stops or waiting to transfer as with fixed schedule / fixed route public transit.

Along La Avenida, the shuttle drops off Greg at Starbucks near his work and Sharon and George at the Microsoft campus. The shuttle turns around, crosses 101, along Middlefield drops off Julie at the county Social Services Agency, and turns into Crittenden Middle School along Rock Street.

As he arrives at the middle school, Mark again realizes that the shuttle drops him off closer to his classroom than when he parked further away in the parking lot. He also again notices that half the parking lot has been repurposed as a community garden. The other half still provides parking for faculty and staff that on occasion use their own autonomous vehicles to run multiple errands after school, and for CalShuttle charging stations.

Mark watches the shuttle leave to begin its next roundup of three to five passengers in adjacent Mountain View neighborhoods for drop-offs at other job centers.

2 CalShuttle: On-demand, point-to-point, fast, 24-hour shuttle rapid transit.

The commuting scenario above introduces CalShuttle, the organizational name for Bay Area shared autonomous vehicles (SAVs). Related generic terminology includes microtransit, shared autonomous vehicles (SAVs), mobility as a service (MAAS), and transportation as a service (TAAS).

This section presents the key characteristics of CalShuttle. Later sections describe: impacts; the CalShuttle agency; capital and operational implementation costs and schedule; future expansions; the supporting analysis; and references.

"It is anticipated that AVs will increase safety and comfort …, and reduce traffic congestions, pollution, fuel consumption, as well as facilitate further the mobility accessibility to disabled and older people. Also, self-driving will decrease the number of accidents and crashes through the vehicle to vehicle communication." Additional benefits include: control of traffic flow, maximize intersection capacity; minimize bottlenecks; comfort and entertainment services; mobility for those unable to drive; and travel speed increase. [Bezai2019a]

Overall, CalShuttle will provide a better transit solution than fixed-route, scheduled options. [Leich2019a]

2.1 On-demand

Using a smartphone, computer, land-line phone, a simple, single-purpose handheld device, or a kiosk on major streets, each rider will request a pickup at or near their location and specify a destination. Pickups will usually occur within 5 minutes.

During commute hours, algorithms will gather riders from nearby pickup locations that have destinations near each other. The algorithms will assure an average 4 riders per trip during commute hours and a 2 riders per trip in weekday non-commute hours, Saturdays, and Sundays.

2.2 Point-to-point or pickup-to-dropoff locations (PUDOs)

Travel will be point-to-point or nearly so with no transfers. Pickup and dropoff will be at or near to each rider's location and destination, often right at the desired address. The solution for the first mile-last mile issue is built-in. [Wiseman2019a]

2.3 Fast

CalShuttle will reduce the total number of vehicles on the road and so will reduce or eliminate traffic congestion which slows down travel. Shuttles will operate at highway speeds on freeways because CalShuttle's overall vehicle reductions will eliminate freeway traffic jams. [Chakravarty2020a, Torchinsky2020a]

CalShuttle will be fast also because the shuttles will be interconnected and aware of each other, so they can accelerate and decelerate in a coordinated fashion. Some slowdowns will occur when a non-autonomous vehicle is detected and the autonomous shuttles allow extra separation for safety. [Adams2020a]

2.4 24-Hour Availability

Without human drivers, Shuttles will be provide the same on-demand point-to-point service 24 hours per day, 7 days per week. This provides anytime service for riders who need to work late at night or early in the morning. This also provides transportation for evening and late-night drinkers; DUI incidents will be nearly eliminated.

2.5 Safe travel

Interconnected shuttles aware of each other will enable them to cross each others' paths without collisions, and to maintain extra distance from non-autonomous vehicles. Shuttles will have crumple zones to protect passengers. Extra safety is provided by seat and shoulder belts. [Adams2020a]

As autonomous computer-driven vehicles, Shuttles will always be paying attention, eliminating accidents due to human driver fatigue, distraction, or medical incidents. Algorithms will detect and avoid other vehicles, pedestrians, bicycles, and animals as well as human drivers do. [Waymo2020a]

Shuttle algorithms will include awareness of the algorithms' own limitations. If a Shuttle does not know how to handle a situation, it will simply stop safely until remote or on-location assistance can be applied. Studies are underway to account for "maximum acceptable risk" to address this characteristic. [Geisslinger2023h]

As contagious diseases continue, close proximity to just 3 to 5 people in a shuttle should be generally safer than to dozens or more on a bus or a train. As supply and demand shift with regulated social distancing measures, microtransit can respond in real-time. On-demand technology allows fixed routes to morph into dynamic lines, managing peak travel times, pre-booking seats, and accommodating evolving safety practices. [Via2020c]

2.6 Resilient

When an accident or disaster occurs, Shuttles will be inherently resilient. Shuttles can be routed around accident locations or damaged roadways. Shuttles will be battery and fuel-cell powered, and able to continue operation for a period of time while charging and refueling are not available. Solar power and industrial-scale batteries can provide a partial level of power for recharging and refueling, as well as hydrogen extraction from Bay seawater.

2.7 Robustly Redundant

Shuttles will automatically make selections among multiple routes, and adjust those selections as traffic conditions change, to arrive as quickly as possible at the destinations. When a Shuttle breaks down, an unassigned replacement Shuttle will be nearby to offload the passengers to resume their journey.

2.8 Scalable Down and Up

As demand varies due to weather, disease, holidays, seasons, and other factors, service availability will automatically scale to match the demand. There will be minimal need to adjust CalShuttle and shuttler operator personnel schedules, except at charging stations and maintenance facilities.

This will become more important as commuting worker demand reduces, with hybrid work-from-home options and 4-day workweeks become the norm. In 2022, it is already difficult for fixed schedule, fixed route transit such as Caltrain, BART, and VTA to maintain sufficient ridership to be viable. [Thompson2022a]

2.9 Easy Boarding

The shuttle floor will be close to curb height, enabling near-level boarding for everyone. Some on-request Shuttles will have ramps, to ease the onboarding of suitcases, walkers, and wheelchairs. [Priddle2020a]

2.10 Personal autonomous vehicles

Many families will choose to own at least one private autonomous vehicle, for more complex non-commuting trips, such as transporting kids to group activities and shopping trips with multiple stops.

3 CalShuttle Impacts

"There are premises to suspect that introducing autonomous and connected vehicles may revolutionize the whole transportation area. Thanks to self-driving cars, disabled people, elders or people without valid driver's license, could safely travel to long distances. … Public and private transportation may change as well, taxis and buses may be replaced by cars on-demand, shared among many passengers, being in motion almost all the time, instantly picking people up on call … reduce demand for parking places and improve space utilization in urban areas - the need for parking space in the United States may be reduced by more than 5.7 billion square meters … reduced demand for parking may reduce number of cars driving in the city center (it is estimated that 30% of traffic congestion in downtown areas in big cities is generated by vehicles cruising for unoccupied parking spot … Passengers will be able to spend their travel time working or relaxing." [Gora2016a]

"In addition, thanks to V2V communication cars could potentially exchange information about their positions, speeds, routes, plans for changing speed or lane, turning, stopping. They could let other cars know about their intentions and collaboratively agree on common driving strategies, which would ensure safety and be in some terms optimal for achieving desired goals. It is estimated that self-driving cars could reduce the number of accidents by 90%, saving many lives and yearly about $190 billion in U.S. … The self-driving revolution is expected to be the greatest thing to happen to public health in the 21st century …" [Gora2016a]

Passengers typically must use another means of transportation to arrive at a union station; whereas when using driverless cars there is no need for the hassle of these connections. As a result, driverless cars will gradually take control of the transportation market. As more and more driverless cars are on the roads, the union stations will slowly but surely fade away from our lives." [Wiseman2019a]

[Shuttle] pooling is the answer to: ameliorate traffic congestion; reduce climate change; social equity; reduce soaring transportation infrastructure costs. [Sperling2018a] Automated connected shuttles (ACSs) can deliver significant improvements in travel delays, energy consumption, and emission reductions. [Akter2021a] A fleet size of 1 SAV per 14 affected people with 5-seat vehicles is the most effective in transporting people to larger buses in an emergency situation. [Lee2022]

"AVs could fundamentally change the way transportation networks are designed …. AV adoption could shape the future of public transit, climate emissions … and access to opportunity." [Bagdoll2024a, MTC2021j]

3.1 Reduces vehicle traffic counts, traffic congestion, and energy usage.

The San Francisco-Peninsula Commute case study (Table 8-1 based on Table 9-1) shows commute period Vehicle counts (Conventionals and Shuttles) with these impacts:

- 31,354 Shuttles will reduce commute periods vehicles on the road by 468,000 or 46% of commuter vehicles and therefore will reduce traffic congestion.
    - This ratio of 1 Shuttle to 15 vehicles reduced aligns with ratios of 5 to 20 from other studies. [Fagnant2014a, Hogeveen2021a, Manders2020e, Othman2022b, Pisarov2021a, Shaheen2020a]
- Studies show that replacing all and bus trips by fleets of shared automated taxis and shuttle busses would result in: 90 per cent or more fewer vehicles, and 37 per cent fewer kilometers traveled by the vehicles. [Manders2020e, Shaheed2018b]
- Smaller reductions will result during weekday non-commute hours and weekends.
- These reductions apply even though CalShuttle also includes the commuters currently using the commuter periods services of Caltrain, SamTrans buses, and VTA buses and light rail.

Shuttles will reduce congestion generated by vehicles cruising for parking spaces, estimated to be as much as 30 percent of traffic congestion .... [Gora2016a, Houssain2026a, Park 2021a, Pisarov2021a, Wiseman2017a]

"Reducing human reaction times and the subsequent traffic waves, can reduce total fuel consumption by up as much as 40 percent." [Bagdoll2024a, Golomb2021a, Othman2022b].

One simulation for Milan reports comparable results:

- 30% usage of 9,500 robotaxis, a 33% acceptance rate of current car users, and 10% peak demand decrease would eliminate traffic congestion (page 5).
- 6-seater robotaxi vehicles with an average of 4 passengers per trip at an average of 25 mph should result in an acceptable 10-minute extra travel time (Figure 7). [d-line2018a]

3.2 Minimizes infrastructure costs through reuse of existing street network.

Our Bay Area streets, expressways, and highways will become our transit network - like subways just not underground, without having to change trains, and departing and arriving close to any destination.

3.3 Eliminates the need for more highway or bridge construction.

Significantly reduced commuter vehicle counts will eliminate the need for more lanes on existing highways as well as eliminate the need for carpool diamond lanes and fee-based express lanes. The need for a new Southern Crossing bridge from Highway 380 to Highway 238 will also be eliminated. [Park2021a]

3.4 Reduces or eliminates household car ownership cost.

"Regardless of the household's income bracket, there seems to be wide consensus in favoring SAVs as they are expected to turn out to be the most affordable alternative." "SAV service boasting low added travel time on shared rides can attract several riders, and when used in tandem with smart pricing to cater to the distribution of WTP, it can be an effective service." [Gurumurthy2020a]

"Due to the high capital costs, but low maintenance and operating costs compared to traditional cars, automated electric vehicles will be more interesting to share rather than to own." [Manders2020e]

"Uber plans to [make] the cost of [driverless] rides so low (between its fleet of human and robot cars) that vehicle ownership becomes obsolete." [Shetty2020a]

Households typically own one car and often two or more. CalShuttle will enable each household to choose to own and maintain at least one less car. For these three counties, assuming 25% of single-car households and 50% of households with two or more cars each reduced by one car, about 500,000 fewer vehicles will be privately-owned. [Census2019a / Table 9-2, Keeney2017a, Martin 2011a, Othman2022a, Shaheen2020a]

Household automobile insurance premium costs will reduce due to the reductions in the number and severity of accidents enabled by automated braking and other accident prevention technologies. Much of that will be replaced by insurance premiums for the private fleet operators, but overall insurance premiums to insurance companies will decrease. [Gatzert2020c]

The average car ownership annual cost is $9561. Families' private automobile ownership cost savings: ***$4.75 billion*** per year (500,000 fewer vehicles x $9500 annual cost savings per vehicle). [AAA2020a]

3.5 Reduces passenger, pedestrian, cyclist, motorcycle injuries and death.

At least ninety percent of automobile accidents are caused entirely or in part by human error. Modeling estimates that always connected, attentive (and sober) Shuttles should eliminate from 33 up to 90 percent or more of these accidents and 27 percent of bodily injuries. Waymo researchers studied more than 56.7 million miles of driving and report that by removing the human driver Waymo achieves reductions in crashes: 92% involving injuries among pedestrians, 82% with cyclists, and 82% involving motorcyclists. [Golomb2021a, Gora2016a, Houssai2026a, Keeney2017a, Othman2022a, Othman2022b, Pisarov2021a, Singh2015a, Smith2013a, Sullivan2025f, Victor2023, Weijermars2022g]

3.6 Improves mobility and employment for our older and disabled residents.

Shuttles will provide more travel non-driving residents with door-to-door service 24/7. Shuttles will improve on existing paratransit services, being available 24/7 with quick arrival times assured by spreading special vehicles throughout the service areas. [Houssain2026a, Jiang2024b, Othman 2022a, Othman2022b, Perrine2018a, Via2020c]

AVs will enable an increase in US labor force participation of people with disabilities by 15 percent, resulting in 9.15 million direct, indirect, and induced jobs, increasing annual income, GDP, and federal tax revenue by $416 billion, $867 billion, and $92 billion respectively. This would also reduce annual federal spending for Social Security SSI and SSDI by $27 billion. [Modicamore2022l]

3.7 Enables converting street parking spaces, parking lots and garages to other uses.

"A fleet of autonomous taxis would drastically reduce the need for parking space in the city and would, therefore, open space for additional lanes to increase the capacity or even make cities are more friendly, greener and livable place." [Horl2017a, Houssain2026a]

Fewer street parking spaces and fewer and smaller parking lots and garages will be needed. Across the U.S., by 2030, autonomous taxis might free up 250 million parking spaces worth $4.2 trillion. Converting parking spaces will add more than $350 billion to homeowner, commercial, and municipal real estate returns in 2030. Replacing all car and bus trips in Lisbon with SAV[s] … will reduce public parking space required by 95 percent. [Houssain2026a, Keeney2017a, Manders2020e, Othman2022a, Othman2022b, Pisarov2021a, Shaheen2018a]

Nearly all shuttles will be active during the rush periods, and most will be active intermittently during non-rush hours. During idle time, shuttles will be strategically parked near where demand has been shown to be high for the next rush period, often curbside. [Wiseman2017a]

3.8 Eliminates the need and cost for corporate shuttle buses.

Shuttles will eliminate the cost and traffic congestion caused by the 1,020 private corporate shuttle buses. Private company annual savings: ***$250 million***. [Stone 2020a]

3.9 Enables productive activities or resting while shuttling.

Drivers of previous single-person commuter vehicles will be freed from paying attention to driving activities. They will be enabled to be active in work, recreation, exercise, or resting while being shuttled. This will reduce commute stress. [Houssain2026a, Othman2022a, Othman2022b, Perrine2018a, Shaheen2020a, Waymo2020a]

4 CalShuttle agency and private vendor shuttles

Private vendors will purchase, own, operate, and maintain the actual Shuttles. Likely companies could include: on-demand rideshare companies like Uber, Lyft; traditional rental-car companies like Hertz, Avis, National, Alamo, Budget; automobile companies such as Ford, GM, and Tesla; and others.

CalShuttle will be a three-county agency arranging and providing services, akin to a airport like SFO does for airlines but with different and fewer services. San Francisco MTA, San Mateo SamTrans, and Santa Clara County VTA will jointly operate this agency.

CalShuttle duties will include:

- Construct and maintain electric and hydrogen charging stations at locations throughout the three counties. Features will include:
  - Automated shuttle drive-up charging connections.
  - Cleaning the shuttles as needed, perhaps including UV treatment.
  - Connections to the electrical grid and to hydrogen supplies.
  - Backup battery and hydrogen storage.
  - Garages for shuttle maintenance by the shuttle providers, including repairs and cleaning.
  - Site security.
- Manage interoperability among shuttle operation companies [Chan2012a].
- Monitor the shuttle providers to assure that their algorithms achieve the target rush period passenger load.
- Monitor the shuttle fleets to assure sufficient accessible support for disabled passengers.
- Manage fare subsidies for various groups, where applicable: low-income, disabled, seniors, students.
- Manage the multi-year transition from Caltrain, SamTrans, and VTA rail, bus, and light rail service to CalShuttle operations.

Charging stations will be automated with one or more technologies, so no human will need to be involved:

- A retractable arm connecting to a charging port at a standard location of the side of each Shuttle.
- A retractable post connecting to a charging port at a standard location on the bottom each Shuttle.
- Wireless charging through coils mounted in the ground below the charging lane.

Wireless charging is being tested and in use. One company's cost target is $3,500 per charger plus installation. Wireless charging should be almost as efficient as wired. [Charlton2021a, Electropedia2021a, Emilio2021a, Muller2022a, Shahan 2020a]

5 Cost-Effective Implementation and Operation.

5.1 Implementation Costs, Savings, and Shift to Private Vendors.

Table 8-2 and Table 8-3 show the parameters and analysis that drive these costs for implantation capital expenditures.

Table 5-1. New Costs

		Taxpayer-Funded	Privately-Funded	
		$Million	$Million	
Entity	Item	New Costs	New Costs	Reference
Vendors	Shuttles purchase		$2,516	Table 7-3, h06
CalShuttle	Chargers and stations	$377		Table 7-3, i36
	New Costs	$377	$2,516	
	10-Year Recovery from Vendors	-$377	$377	
	10-Year Totals	$0	$2,893	

Shuttles will have low floors, near or at the existing height of street curbs and sidewalks, enabling near-level boarding. This will minimize or eliminate steps up that are common with buses; and the need for special boarding platforms that are common with light rail. [Priddle2020a]

This approach will transfer all capital expenses from the government agencies of SamTrans and VTA to the private vendors who will purchase, own, operate, and maintain the Shuttles. The initial capital cost of the taxpayer-funded investments will be amortized over a 10-year period, and charged back to the private Shuttle operating vendors as part of the CalShuttle service fee.

This analysis does not include taxpayer-funded standardized pavement markings, signage, and other infrastructure will enable AVs to operate better, [FHWA2020a]

This analysis does not include taxpayer-funded capital expenditures for Caltrain corridor grade-crossing gate and other improvements to handle California High Speed Rail trains.

5.2 Operational Costs, Savings, and Fares.

Table 8-4 shows the parameters and analysis that drive these costs for operational costs, and fares.

Key factors in operational costs for shared autonomous Shuttles include:

- Eliminates the driver labor costs that comprise 80% of per-mile cost [Shetty202a].
- Spreads operational costs across multiple passengers and trips.
- As with any EV, Shuttles reduce energy costs. [VanderWerp2021a]
- Reduces or eliminates the maintenance costs for fixed infrastructure such as Caltrain and light rail tracks.

Table 8-4 details that 100 per cent fare recover is possible with the following parameters (parameter IDs):

- 31,354 CalShuttle-administered, private vendor-operated Shuttles (a54)
- 505 million annual passenger trips (e30)
- 155 million annual Shuttle trips (e18)
- 3.3 average Shuttle passenger load per trip: 4 during commute periods, fewer other times (n24)
- 20.3 mile average Shuttle trip distance (f03)
- $6.39 cost per 20.3 mile Shuttle commuter trip (n09) or $0.31 per Shuttle trip mile (n12)
- $1.96 fare per Shuttle passenger (n18), or about $0.097 per passenger mile (n21) for a 20.3 mile trip

This $1.96 fare is similar to an acceptable fare of $2 reported in one study. [Shaheen2020a]

City-operated and subsidized ride-hailing services fares in Connecticut - $1.75 - and Palo Alto - $2 to $4 - are in line with this study's $1.96 fare - but the SAV fare requires no government subsidy. [Moritz2025d, Palo Alto]

$0.097 per passenger-mile is consistent with other Shuttle per mile (not per passenger mile) estimates that range from $0.20 to $0.37. [Keeney2017a, Othman2021a, Sperling2018a], but is lower than one per passenger mile estimate of $0.37 [Bosch2017a]. $0.097 per passenger-mile is much less than the over $0.60 per passenger-mile that one survey of Texas residents said they would be willing to pay for SAV service. [Gurumurthy2020a]

$0.097 per passenger mile is much less that current public transit systems spend on human driver, fixed-route, fixed-schedule, large vehicle systems (e.g., busses). For example, SamTrans cost per passenger-mile was $2.29 for 2014 to 2017. [Othman2022b, Pierlott2028a]

Vendor-operated Shuttles transfer all costs for Shuttle operations, CalShuttle charging stations and office operations, and CalShuttle capital equipment amortized costs to the private vendors. No ongoing government subsidy is required, except possibly for special classes of passengers such as: low-income; students; seniors; and special assisted shuttles with ramps.

CalShuttle and the private Shuttle vendors may choose to adjust this fare schedule for the following characteristics:

- Charge each passenger per passenger-mile traveled.
- Fare reductions for various groups: low-income, students, seniors, disabled.

Section 3.8 indicates that San Francsico, San Mateo, and Santa Clara Counties household will likely realize annual savings of $4.75 billion through reduced ownership of personal vehicles.

Section 3.13 indicates that Shuttles will eliminate the need for corporate shuttle buses, for an annual savings of $250 million. [Stone2020a]

"When on-demand networks are implemented in a smart way, communities can actually save money compared to their previous fixed route services, unlocking broader benefits that pay back the initial investment many times over." [Voia2020a]

6 CalShuttle - The Future of Bay Area Transit.

6.1 Advocacy

The study advocates for this CalShuttle approach based on: the improved service characteristics described in Section 1; and the financial and other beneficial impacts described in Section 2 especially those that will accrue to reduced government capital and operational costs. Not all known and potential issues have been addressed yet, by 2025 … but they are being addressed, quickly.

Dynamic carpooling services will enable drivers and passengers to easily share a car. This will reduce cost, fuel consumption, pollution, and traffic congestion. Vehicle sharing will not only be convenient but necessary. [Tyagi2016j]

6.2 … AND Prediction

This study both advocates for this approach but also simply reports and predicts what is very likely to occur whether government advocates for it or not.

Ride-sharing services such as Uber and Lyft have shown that the on-demand, point-to-point model is popular. The financial benefits and profit opportunities described in Sections 2 and 5 are already attracting investments by private corporations to provide these services. Ride hailing services are already replacing the use of public transportation due to low wait times and increased flexibility. In 2023, the City of Palo Alto implemented Palo Alto Link, a city-operated point-to-point rideshare service for destinations within the city. [Hansen2022k, PaloAlto2024l, Shetty2020a]

"Self-driving cars are inevitable. It is only a question of time. Morgan Stanley estimates that autonomous vehicles can save just the US economy a total of $1.3 trillion per year. The technology will disrupt the transportation industry from passenger car to mass transit. … The main challenge to bringing autonomous technology is the unavoidable tens of thousands of dollars in additional cost per vehicle. <u>In the near term, ride-hailing business will be the first to have a financially-viable reason to replace human drivers. For this reason, robotaxis are expected to come before mainstream autonomous passenger vehicles</u>. As we transition to an access economy, urban consumers will increasingly favor a driverless-car booking over car ownership." [Golomb2021a; underling added]

"… shared AVs have the potential to significantly reduce the average waiting time and trip costs when compared with the current transit service, which means that shared AVs will be a strong competitor to the transit service and might attract public transit users. Thus, transit agencies should be aware of this new coming disruption to the transportation system or else they will incur significant losses; in particular, AVs will be available sooner or later." [Othman2022a]

"Carpooling is poised to address the current issues in transportation such as car ownership, traffic management, transport economy, time management … has been proved beneficial in traffic congestion control, the effect on the environment, economy, rush hour problems. However, these advantages have brought many challenges that the research community has tried to address, and the current carpooling service providers have adopted few." [Zafar2022]

Some observers fear that SAVs would undercut public transit such buses and trains. This paper advocates that SAVs will BE the primary public transit of the future - privately operated but publicly supervised.

6.3 The beginnings of a Bay Area-wide network
For the purpose of bounding the scope of analysis, this study was limited to the three Peninsula counties. This distinction is arbitrary - it is likely that such CalShuttle services will grow organically within all nine Bay Area counties in parallel.

Even if CalShuttle does start only in the three Peninsula counties, the first natural service extension would be across the bridges that connect these counties to Marin, Contra Costa, and Alameda counties.

6.4 Even Longer Distances
It is likely that CalShuttle would quickly expand to more distant popular destinations, for example Sacramento, the Sierras, and Bakersfield. Such trips would not take less time than personal driving, but businesspeople and families could make effective use of time for such 2-to-4-hour trips, as described in section 3.13.

Shuttles will operate at highway speeds on freeways because CalShuttle's overall vehicle reductions will eliminate freeway traffic jams. [Chakravarty2020a, Torchinsky2020a]

"Americans expect much of their long-distance travel (for trips over 50 miles, one-way) to shift toward AVs and SAVs. For example, nearly 50% of trips between 50 and 500 miles (one-way) are expected to eventually take place in an AV or SAVs …" [Gurumurthy2020a, Perrine2018a]

Autonomous vehicles including autonomous shuttles could be the basis for semi-high-speed travel on highways. An "autonomous autobahn" with vehicle speeds up to 120 mph could be added to California's highways 5 and 99 for much less cost than the current California High Speed Rail plan, perhaps entirely paid for by vehicle tolls. [Jackson2019a]

6.5 Timeframe: Early 2030s.
Many sources predict many timeframes from 2021 to decades from now for autonomous vehicle acceptance and adoption: 2020 to 2030 [MTC2018f]; 2021 [McBride2021a]; 2024 for Tesla, many others shortly thereafter [Johnson2021a]; 2025 [Dans2021f], [Newman2021a]; 2025 to 2030 [Faggella2020a]; 2026 [Pinto2020a]; 2030 [McKinsey2021a], [Forsgren2018a], [Litman2021a], [Potgeiter2021a]; decades from now [Gupta2021a].

In planning to launch a self-driving car with a detachable steering wheel in 2023, China's Jidu indicates "… that the technology, which many have dismissed as impossible until many years from now, has already reached a level of maturity thanks to the application of machine learning. The sheer size of the Chinese automotive market, equivalent to the United States, Europe and Japan combined, should generate economies of scale that would make the technology available relatively quickly." [Dans2022l]

Many activities and studies in the early 2020s indicate that development and implementation will progress quickly:

- Autonomous taxi, rideshare, and delivery services (latest to earlier)
    - Waymo's driverless robotaxis have already captured 27 percent of ridesharing in San Francisco. [Sullivan2025f]
    - Connecticut has implemented a human-driver subsidized ride-hailing system in 17 cities. [Moritz2025d]
    - Waymo approved to expand driverless taxi services in San Mateo County and as far south as Sunnyvale. [Baron2024a]

  - San Jose considering a fleet of 200 robotic shuttles San Jose Airport and downtown San Jose, using a dedicated new guideway. [Greschler2023d]
  - Bishop Ranch business park has driverless autonomous shuttles. [Wittner2023d]
  - "Lyft … will test self-driving taxi rides in Las Vegas … starting in 2023." [Akers2021a, Davalos2021a, IntelTransport2021a]
  - Lyft, Ford, and Argo AI announced the launch of an autonomous ride-share service in Miami in 2022. [IntelTransport2022a]
  - Walmart and Kroger have driverless vehicles operating for grocery delivery. [Kovacevich2022a]
  - Uber Eats deliveries will pilot driverless deliveries in Santa Monica in 2022. [Davalos2021a]
  - Waymo to start operating autonomous vehicles in Los Angeles in the coming months. [Waymo2022j]
  - Lyft and Motional have provided over 100,000 robotaxi rides (with safety drivers) from 2018 to 2021, without any at-fault road incidents. [Akers2021a]
  - "Tesla … will soon… operate a fleet of robotaxis." [Dans2021f]
  - "Waymo, Didi or AutoX … already operate fleets of fully autonomous cabs … [in] several cities in the US, China and Russia." [Dans2021f]
- On-demand transit services (not yet autonomous)
  - SamTrans door-to-door on-demand pilot in East Palo Alto and Half Moon Bay [PADailyPost2023a]
  - Palo Alto Link on-demand rideshare service. [Sheyner2023b]
  - Richmond, CA launched an on-demand transit service in April 2022. [Via2022d]
- Manufacturer developments including trucks
  - China's Jidu Automotive will marking a self-driving car in 2023 for about $55,000. [Dans2022l]
  - Ford enhances Advanced Driver Assistance Systems (ADAS) in Mustang Mach-E in fall of 2022. [Hamblen2022i]
  - The truck driver shortage will drive the deployment of autonomous trucks. [Kovacevich2022a]
  - "The Amazon-owned Zoox "robotaxi features a massive 133 kWh battery pack claimed to provide up to 16 hours of operation on a single charge. … and can hit a top speed of 75mph." [Chakravarty2020a]
  - GM has announced the Cruise Origin SAV with an expected cost that will be half that of an electric SUV. [Yoney2020a]
- Government initiatives
  - Livermore Amador Valley Transit Authority and the City of Dublin are sponsoring a systems engineering feasibility project regarding a first/last mile transit service from East Dublin/Pleasanton BART station to nearby business, residential, and commercial developments. [WheelsBus2023i]
  - The San Francisco Bay Area Metropolitan Transit Commission (MTC) is sponsoring a "technical assistance grant program to fund SAV technology pilot/deployment projects." [MTC2023b]
  - The National Academies have provided a framework for states and localities to evaluate AV safety. [BTSCRP2022a]
  - San Mateo County is looking ahead 5, 10, 20 years and considering autonomous vehicles including shuttles for public and private transportation. [Bowning2021a]

Key factors in Shuttle implementation and adoption include "technology interoperability and integration, enhanced casual carpooling, and public policy." [Chan2012a]

Studies show that commuter public transit usage is much higher when residences and job destinations are within 1/2 mile of a transit stop. CalShuttle transit "stations" - pickup and dropoff locations (PUDOs) - will be within 2 blocks of the passengers home and work locations, so passenger acceptance will be high. Also, access to HOV or Express lanes has a positive influence on carpools; by reducing overall congestion, CalShuttle will have an effect similar to HOV and Express lanes. [García-Palomares2018a, FHA2022a, Hunter2023c, Kolka2011a, MWCOG2016a, Wiseman2019a]

CalShuttle addresses all of these "… casual carpooling success factors: 1) a time savings incentive for drivers; 2) monetary savings for passengers; 3) pickup locations near freeways, residences, parking, or public transit stops; 4) a common dropoff location; 5) reliable public transit for the return trip; and 6) an HOV requirement of three or more occupants." [Shaheen2016a]

"… carpooling will be part of the urban life in a very short time. … technology has advanced sufficiently to make it possible to efficiently coordinate the travel of the different people in a pool." [Dans2017a]

"… our low disruption scenario only foresees advanced AVs (level 4 and 5) with a 2% share of light vehicle sales by 2030 rising to 10% by 2040. However, should the revolution follow our high disruption scenario where <u>AVs comprise a 30% share of light vehicle sales by 2030</u> and 50% by 2040 …" [Forsgren2018a; underlining added]

Even as early as 2022, between 40 and 50 percent of young adults in one survey were extremely or somewhat comfortable with riding in an AV for everyday travel or relying on shared CAVs. [Bagli2022k]

"I believe we'll reach a tipping point with autonomous vehicles within the next decade. … We've made tremendous progress on autonomous vehicles, or AVs, in recent years, and I believe we'll reach a tipping point within the next decade. When it happens, AVs will change transportation as dramatically as the PC changed office work." Turcking, deliveries, taxis and rental cars will precede private AV ownership. [Gates2023c]

SAVs will be implemented first in controlled situations, limited to specific communities and simple safe roadways, and perhaps low-traffic rural areas. Then SAVs will expand incrementally to larger, more varied urban and suburban areas, and finally even to handle locations and roadways never visited before by an SAV. [Levin2023c; and Current Activities earlier in this section]

Considering all of these predictions and investigations, this study presumes a middle date of 2030 for the beginning of a critical mass of production and acceptance. A 65 percent acceptance rate for using AVs within 3 to 4 years after introduction led to the 2033 date in Section 1. One study predicts a similar acceptance rate of 56 per cent. [Biermann2023, Othman2021a]

This study presumes that it is likely that this CalShuttle approach can and will be funded by private corporations and implemented more quickly than the funding, planning, and construction for the CalTrain and VTA projects listed would be completed by the county and city governments.

6.6 Risks and Challenges

6.6.1 Current studies

Studies highlight current risks and challenges, which are being addressed by research, design, and testing.

At autonomous level 2, drivers may not understand that they must pay full attention. At level 3, the driver's reaction time added to the system's reaction time may be too long for an effective response. Level 4 may require road infrastructure investments that only rich nations or localities can provide, perhaps creating a new "digital divide" associated with AVs. [Polidori2018d]

AV issues include: safety, especially for pedestrians; reliability of the onboard systems; liability and accountability, between the AV system and the occupant(s); and security of the AV system. [Memon2022g]

6.6.2 Parallels with newfangled automobiles in the 1900s

Between 1900 and 1913, the newfangled technology, the automobile, replaced almost all horse-drawn vehicles in New York City. Initially, dedicated highway and expressway lanes might could help autonomous vehicle adoption and operation. [Rajib2017a, Litman2021b]

In the 1900s, the budding automobile industry had risks and challenges that parallel those of AVs today. Automobiles were:

- Unreliable, needing frequent repairs.
- Nearly useless on muddy roads or steep hills, or in winter.
- Unsafe with the usually inexperienced drivers, and for pedestrians.
- Noisy (although mufflers where quickly introduced).
- Hard to start, especially gasoline engines.
- Expensive (although mass production reduced prices quickly).

But the benefits of automobiles outweighed these early disadvantages:

- Speed - an automobile could travel much faster for longer than any horse-drawn wagon.
- Availability - refilling a gas tank takes much less time than feeding and resting a horse.
- Power - larger engines made possible larger loads or hauling than possible with horses or oxen.
- Less pollution and odor - than horse manure.
    - In New York in 1900, the population of 100,000 horses produced 2.5 million pounds of horse manure per day, which all had to be swept up and disposed of. [Fee2004i]

The most effective use of automobiles required government investment in infrastructure in the form of paved roads to replace dirt roads, and the continuing upgrading of paved roads over decades. The most effective use of SAVs will also require some infrastructure enhancements over years and decades. (Those potential costs are not included in this study.) [Kosuru2023d]

The advantages of automobiles were compelling, and technology improvements in automobiles and roads in the 1910s and 1920s overcame most of the deficiencies of automobiles. Similarly, the advantages of SAVs are compelling in the 21st century, and technology and infrastructure improvements will address the current challenges.

7 Changes in Government Approaches: Cost Savings and Questions

If this study is correct and a CalShuttle approach is both beneficial and inevitable, this should lead to questions about current investments in attention and funding:

- Should we suspend planning and arranging funding for Caltrain grade separations, DTX, and the Dumbarton Corridor projects?
- Should we suspend planning and arranging funding for the BART Santa Clara extension?
- Should we refocus city and county government attention on other issues, such as housing, police and fire department services, water and power infrastructure, and so on.

Table 7-1. Capital Expenditure Eliminations

	Cost Avoidance Savings	Taxpayer	
		$Billion	
Entity	Item	Savings	Reference
Caltrain	Grade Separations	$10.2B	Section 7.3
Caltrain	DTX	$6.7B	Section 7.3
Caltrain	Dumbarton	$2.4B	Section 7.4
VTA	BART Extension	$12.2B	Section 7.5
	Savings	$31,5B	

7.1 Replaces Caltrain commuter operations AND reduces commuter traffic.

The San Francisco-Peninsula Commute case study (Table 8-1) shows how CalShuttle could replace the Caltrain commuter train service and still reduce overall commuting automobile and shuttle vehicle traffic.

7.2 Retains some Caltrain capacity.

Some Caltrain Stadler KISS cars and operations support would be retained to service events at Oracle Park, Chase Center, Stanford, SAP Arena, PayPal Park, and Levi's Stadium. Also freight operations would continue.

CalShuttle shuttles will work well for dispersed starting points and destinations spread out over multiple commuting hours as well as for off-hours on-call service. Large population events with a single location and arrivals and departures concentrated in very short time frames will be better served by high-volume transit connecting to CalShuttle for the last mile.

7.3 Eliminates the cost of Caltrain Corridor grade separations and DTX.

Only these trains will make use of the Caltrain Corridor route:

- Caltrain for large events, mostly off-hours and weekends.
- California High Speed Rail at a peak of 4 trains per hour in each direction.
- Infrequent freight traffic scheduled to avoid CA HSR peak hours.
- Nostalgic and holiday trains during off-hours and weekends.
- Rare freight trains to support national defense (STRACNET) [Tiller2009a].

With auto traffic disrupted across and alongside the Caltrain Corridor at most every 7.5 minutes during CA HSR peak hours, grade separations will no longer be needed. This will also avoid the years-long disruption to automobile traffic and neighborhoods due to the construction of grade separations.

The timeframe for completing grade separations along the entire Caltain Corridor would almost certainly be decades. Caltrain reports that a single grade separation project takes 10 to 15 years, from initial planning to completion. Many cities have not yet decided on grade separation design preferences nor secured funding. [Caltrain2023a]

This will free up city budgets, and enable city governments to attend to other high-priority needs such as general and low-income housing, police and fire department services, infrastructure, and so on.

CalShuttle will also eliminate the need for the Caltrain / High-Speed Rail Downtown Extension (DTX) from 4th and King to the Transit Terminal.

Government transit agency capital cost savings: ***$16.9 billion*** -
for grade separations **($10.2 billion**) and DTX **($6.7 billion**). [Caltrain2021a, Cauthen2019a, King2023a]

7.4 Replaces the Dumbarton extension between Redwood City and Union City.

As CalShuttle extends beyond the three Peninsula counties across the Dumbarton and San Mateo Bridges, it will eliminate the need for the Dumbarton rail corridor option, which range in cost from $2.43 billion to $3.32 billion.

Government transit agency capital cost savings: At least ***$2.4 billion***. [Dong2021a]

7.5 Replaces the VTA BART extension in Santa Clara County.

The VTA BART Extension case study (Table 8-5) shows how CalShuttle would replace the BART extension from the Berryessa BART station to Santa Clara.

Low projected ridership on this BART extension might make it a cost-ineffective and politically untenable project. [Kamisher2023c]

As with the Caltrain Corridor, will also avoid the years-long disruption to automobile traffic, businesses, and neighborhoods due to the construction of tunnels and stations.

Government capital cost savings: ***$12.2 billion***. [Greschler2023j]

7.6 Replaces SamTrans and VTA commuter operations.

The San Francisco-Peninsula Commute case study (Table 8-1 based on [BayAreaMetro2016a / Table 9-1]) shows how CalShuttle would replace the SamTrans and SamTrans bus service and the VTA light rail commuter service, and still reduce overall commuting automobile and shuttle vehicle traffic.

7.7 Retains some SamTrans and VTA bus and light rail capacity.

Some bus and light rail vehicles and operations support would be retained to service events at Oracle Park, Chase Center, SAP Arena, PayPal Park, Levi's Stadium, CEFCU Stadium, and Excite Ballpark.

8 The Analysis

Note: This analysis is based on 2016 travel patterns across 3 counties. This does not include consideration of the factor of full-time or part-time remote/non-commuting work that rose after the Covid pandemic.

8.1 Scope: San Francisco-San Mateo-Santa Clara Travel

The travel scope of this analysis includes these Counties:

- San Francisco to and from San Mateo
- San Francisco to and from Santa Clara
- San Mateo to and from Santa Clara
- Within San Mateo
- Within Santa Clara

Travel within densely-populated San Franciso is excluded, assuming that travel entirely within the City will continue use San Francisco Muni buses/trolleys, taxis, and other existing means of transportation.

8.2 Legend

Term	Definition
Charger port	An electric or hydrogen charger port for one SAV Shuttle at a time
Charger	A power supply that may have multiple charger ports
Charging stations	One or more chargers in one location, some with maintenance facilities
Conventional	Current gasoline or diesel passenger auto, van, or truck
Conv pass trips	Count of passenger trips via Conventionals
Conv trips	Count of trips by Conventional vehicles
Shuttle	Shared autonomous vehicle (SAV) 8+ passenger van
Shuttles	Count of Shuttles
Shut pass trips	Count of passenger trips in Shuttles
Shuttle trips	Count of trips by Shuttles
Vehicle	Includes both Conventional and Shuttle vehicles
Veh pass trips	Count of passenger trips in Vehicles
Vehicle trips	Count of trips by Vehicles
Gray cells	Adjustable parameters

8.3 Comparisons to Other Studies

This study's analysis concur with other studies and simulations with similar results:

- "3,000 four-passenger cars could serve 98 percent of taxi demand in New York City, with an average wait-time of only 2.7 minutes." "95 percent of demand would be covered by just 2,000 ten-person vehicles, compared to the nearly 14,000 taxis … in New York City." "Using data from 3 million taxi rides, the new algorithm works in real-time to reroute cars based on incoming requests, and can also proactively send idle cars to areas with high demand - a step that speeds up service 20 percent …" [Conner-Simons2016a]
- An AV fleet of 100,000 vehicles could replace 1.1 million commuting private cars with shorter wait times. [Bischoff2016a]

8.4 The Tables

Section 8.4.1 describes the parameters and references that drive this analysis.

Table 8-1. Counts of Passenger Trips and Shuttles

	Source: [Bay Area Metro2016a]	https://data.bayareametro.gov/dataset/Vital-Signs-Commute-Patterns-Bay-Area/c33n-96bi															
		Settable paramters are in gray				**See "CalShuttle - Mike Forster - v3.5" for parameter settings, references**											
Table 8-1. Counts of Pass Trips and Shuttles		Unit	(F)actor	Totals	Formulas												
a01	**A: Weekday Commuter Conversions to Shuttles**					Drove alone	2-person car-pool	3-person car-pool	4-person car-pool	5-or-6-person car-pool	7-or-more-person car-pool	Bus (VTA + Sam-Trans)	Street-car or Trolley (VTA Light Rail)	Rail-road (Cal-train)	Taxi	Motor-cycle	Other
a02	**One-Way, Morning or Evening Commute Period**																
a03	Passengers among 3 counties	Conv pass trips		1,167,860	a03	942,630	104,140	18,365	6,050	3,250	1,810	45,995	2,045	27,025	1,430	4,595	10,525
a06	Passenger per Conventional loading	factor			a06	1	2	3	3	5.5	7				1	1	1
a09	**Conventional trips**	Conv trips		**1,021,120**	a09=a03/a06	942,630	52,070	6,122	2,017	591	259	*832*	*50*	*0*	1,430	4,595	10,525
a12	% passengers change to Shuttles	factor			a12	65%	65%	65%	65%	65%	65%	65%	65%	65%	65%	10%	10%
a15	**Passengers change to Shuttles**	Shut pass trips		**750,793**	a15=a9*a12	612,710	67,691	11,937	3,933	2,113	1,177	29,897	1,329	17,566	930	460	1,053
a18	Passengers per Shuttle loading	factor			a18	4	4	4	4	4	4	4	4	4	4	4	4
a21	**Total Shuttle trips**	**Shuttle trips**		**187,698**	a21=a15/a18	153,177	16,923	2,984	983	528	294	7,474	332	4,392	232	115	263
a24	Passengers continuing Conventionals	Conv pass trips		417,067	a24=a03-a15	329,921	36,449	6,428	2,118	1,138	634	16,098	716	9,459	501	4,136	9,473
a27	**Continuing Conventional trips**	**Conv trips**		**365,399**	a27=a24/a06	329,921	18,225	2,143	706	207	91	0	0	0	501	4,136	9,473
a30	Change in Conventional trips	Conv trips		-655,721	a30=a27-a09	-612,710	-33,846	-3,979	-1,311	-384	-168	-832	-50	0	-930	-460	-1,053
a33	**New total Vehicle trips**	**Vehicle trips**		**553,097**	a33=a21+a27	483,098	35,147	5,127	1,689	735	385	7,474	332	4,392	733	4,250	9,736
a36	**Change Conv to Vehicle trips**	Vehicle trips		**-468,022**	a36=a33-a09	-459,532	-16,923	-995	-328	144	126	6,642	282	4,392	-697	-345	-789
a39	**% Change Conv to Vehicle trips**	%		**-45.8%**	a39=a36/a09	-48.8%	-32.5%	-16.3%	-16.3%	24.4%	48.8%	798.3%	564.6%	n/a	-48.8%	-7.5%	-7.5%
a42	Total Shuttle trips	Shuttle trips		187,698	a21												
a45	Shut trips per period, Shuttles needed	Shuttles	7	26,814	a45=a42/F												
a48	% Increase for peak hour	Shuttles	8.4%	2,261	a48=a45*F												
a51	% Spare Shuttle ratio	Shuttles	8.5%	2,279	a51=a45*F												
a54	**Total Shuttles needed**	Shuttles		**31,354**	a54=a45+a48+a51												
a57	**Conventionals replaced per Shuttle**	count		**15**	a57=a36/154												
a61	**Round-Trip, Both Morning+Evening Commutes**																
a63	Passengers change to Shuttles	Shut pass trips	2	1,501,586	a63=a15*F												
a66	Conventional trips	Vehicle trips	2	2,042,240	a66=a09*F												
a69	New total Vehicle trips	Vehicle trips	2	1,106,195	a69=a33*F												
a72	Change Conv to Vehicle trips	Vehicle trips		-936,045	a72=a69-a66												
a75	% Change Conv to Vehicle trips	%		-45.8%													
a78	Total Shuttle trips	Shuttle trips	2	375,397	a75=a24*F												
a81	**Trips per Shuttle**	Shuttle trips	2	**14**	a78=a45(F)*F												
b01	**B: Weekday Non-Commute Conversions to Shuttles, and 5-Day Week Totals**																
b03	Both periods Conventional trips	Conv trips		2,042,240	a66												
b06	% Non-Commute / Commute trips	Conv pass trips	40%	816,896	b06=b03*F												
b09	% passengers Change to Shuttles	Shut pass trips	25%	204,224	b09=b06*F												
b12	Pass per Shuttle, Shuttle trips	Shuttle trips	2	102,112	b12=b09/F												
b15	Weekday Shuttle trips per Shuttle	Shuttle trips		3.3	b15=b12/a54												
b18	Typical max weekday trips per Shut	Shuttle trips		17.3	b18=a78+b15												
b21	**Typical max 5-day trips per Shuttle**	Shuttle trips	5	**86.3**	b21=b18*F												
b24	Weekday Shuttle trips	Shuttle trips		477,508	b24=a78+b12												
b27	**5-day Shuttle trips**	Shuttle trips	5	**2,387,542**	b27=b24*F												
b30	Weekday passengers	Shut pass trips		1,705,810	b30=a63+b09												
b33	**5-day Shuttle passengers**	Shut pass trips	5	**8,529,050**	b33=b30*F												
c01	**C: Saturday Conversions to Shuttles**																
c03	Weekday Veh trips	Veh trips		2,859,135	c03=b03+b06												
c06	% Saturday vs. Weekday trips	Veh pass trips	93%	2,658,996	c06=c03*F												
c09	% passengers change to Shuttles	Shut pass trips	25%	664,749	c09=c06*F												
c12	Pass per Shuttle, Shuttle trips	Shuttle trips	2	332,374	c12=c09/F												
c15	**Saturday trips per Shuttle**	Shuttle trips		**10.6**	c15=c12/a54												
d01	**D: Sunday Conversions to Shuttles**																
d03	Weekday Trips	Veh trips		2,859,135	c03												
d06	% Sunday / Weekday trips	Veh pass trips	73%	2,087,169	d06=d03*F												
d09	% passengers change to Shuttles	Shut pass trips	25%	521,792	d09=d06*F												
d12	Pass per Shuttle, Shuttle trips	Shuttle trips	2	260,896	d12=d09/F												
d15	**Sunday trips per Shuttle**	Shuttle trips		**8.3**	d15=d12/a54												
e01	**E: Weekly and Annual Totals for Shuttles**		Weeks/Yr														
e06	5-day Shuttle trips	Shuttle trips		2,387,542	e06=b27												
e09	Saturday Shuttle trips	Shuttle trips		332,374	e09=d12												
e12	Sunday Shuttle trips	Shuttle trips		260,896	e12=d12												
e15	Total full week Shuttle trips	Shuttle trips		2,980,813	e15=e06+e09+e12												
e18	**Total annual Shuttle trips**	Shuttle trips	52	**155,002,277**	e18=e15*F												
e21	Average weekly trips per Shuttle	Shuttle trips		105.2	e21=b21+c15+d15												
e24	**Average annual trips per Shuttle**	Shuttle trips	52	**5,471**	e24=e30*F												
e27	Total weekly Shuttle passengers	Shut pass trips		9,715,591	e27=b33+c09+d09												
e30	**Total annual Shuttle passengers**	Shut pass trips	52	**505,210,734**	e30=e18*F												
e33	**Overall avg Shut passengers per Shut trip**	Pass per Shut		**3.3**													

Table 8-2. Shuttle Miles

Table 8-2: Shuttles Miles: Range, Annual			Unit	(F)actor	Totals	Formulas
	f01	**F: Shuttle Range**				
	f03	Nominal miles per commuting trip	miles	20.3		f03
	f06	Increase factor for deadheading	%	50%	30.5	f06=f03*(1+F)
	f09	Typical max weekday trips, mileage	Shuttle trips	17.3	525	f09=f06*b18
	f12	Shut range margin, nom range at 100% chg	miles	50	575	f12=f09+F
	f15	% charging target, daily travel range	miles	70%	822	f15=f12/F
	f16	% kWh loss for AI, nominal target range	miles	12%	723	f16=f15/F
	f18	**Weekday charges, target range/shuttle**	miles	3	**241**	f18=f15/F
	g01	**H: Annual Mileage Total and Per Shuttle**				
	g03	Total annual Shuttle trips	Shuttle trips		155,002,277	g03=e18
	g06	**Miles - per trip, total annual**	miles	30.5	**4,719,819,334**	g06=h03*f06
	g09	Total Shuttles	Shuttles		31,354	g09=a54
	g12	**Annual miles per Shuttle**	miles		**150,533**	g12=g06/g09

Table 8-3. Capital Costs

Table 8-3. Capital Costs: Shuttles, Chargers			Unit	(F)actor	Totals	Formulas
	h01	**F: Shuttles Capital Costs**				
	h03	Total Shuttles needed	Shuttles		31,354	h03=a54
	h06	**Shuttles capital cost each, total**	$Million	$40,000	**$1,254**	f06=f03*F
	h09	Shuttles operational life	years	10		f09
	i01	**G: Chargers, Charging Stations Capital Costs**				
	i03	Weekday charges per Shuttle, total	sessions	3	94,062	i03=h03*f18(F)
	i05	Charger port sessions/hour, /daily	count	2	48	i05=24*F
	i06	Total Level 3 charger ports	chargers		1,960	i06=i03/i05
	i09	**Charger port cost, each and total**	$Million	$80,000	**$157**	i09=i06*F
	i12	Charging stations primary locations	count	5		i12
	i15	**Electrical substations cost, each, total**	$Million	$11	**$55**	i15=i12(F)*15(F)
	i18	Weekday miles total for all Shuttles	miles		18,043,288	i18=a54*f12
	i21	kWh - per mile, per day, all Shuttles	kWh	0.35	6,387,324	i21=i18*F
	i24	Days, total kWh storage	kWh	0.50	3,193,662	i24=i21*F
	i27	**Battery storage cost - per kWh, total**	$Million	$65	**$208**	i27=i24*F
	i30	**Charging station costs, total**	$Million		**$419**	i30=i09+i15+i27
	i33	Charging stations land costs	$Million	$0	**$0**	i12
	i36	Total Capital Costs	$Million		**$1,674**	i36=h06+i30
	i39	Charging stations operational life	Years	10		i39=i15

Table 8-4. Costs, Annual and Per Passenger

Table 8-4: Costs: Annual Total,Per Passenger			Unit	(F)actor	Totals	Formulas
	j01	**J: Electricity**				
	j06	Total annual Shuttle miles	miles	30.5	4,719,819,334	j06=j03*F
	j09	kWh - per mile, total for all shuttles	kWh	0.35	1,670,816,044	j09=j06*i21(F)
	j12	**Annual total electricity cost all Shuttles**	$Million	$0.14	**$235**	j12=j09*j12(F)
	k01	**K: Annual Costs, per Shuttle and all Shuttles**				
	k06	Annual amortized financing	$	7%	$5,573	k06 (see Notes)
	k09	Annual insurance	$		$1,202	k09 (see Notes)
	k12	License, regisration, taxes	$		$851	k12 (see Notes)
	k15	Maintenance, repair, tires per mile	$	$0.06	$9,032	k15=h12*F
	k18	**Total annual expenses per Shuttle**	$		**$16,658**	k18=sum(k06…k15)
	k21	Total Shuttles needed	Shuttles		31,354	k21=a54
	k24	**Total annual expenses, all Shuttles**	$Million		**$522**	k24=k18+k21
	l01	**L: Charging Station Expenses (all Chargers)**				
	l06	Annual amortized financing	$Million	7%	$58	l06 (see Notes)
	l09	Annual maint, per Charger and all Chargers	$Million	$400	$1	i09=g12*F
	l12	**Total annual Chargers expenses**	$Million		**$59**	l12=l06+l06
	m01	**M: Overhead, Profit Margin, CalShuttle**				
	m03	Subtotal elec., expenses, stations	$Million		$817	m03=j12+k24+l12
	m06	CalShuttle admin. overhead addition	$Million	3%	$25	m06=m03*F
	m09	Subtotal vendor, CalShuttle admin	$Million		$841	m09=m03+m06
	m12	Vendor gross margin addition	$Million	15%	$148	m12 (see Notes)
	m15	**Total annual vendor costs**	$Million		**$990**	m15=m09+m12
	n01	**N: Cost per passenger trip**				
	n03	Total annual Shuttle trips	Shuttle trips		155,002,277	n03=e18
	n09	**Cost per Commuter-length Shut trip**	$		**$6.39**	n09=m15/n03
	n12	**Length, cost per Shut commuter trip mile**	$	20.3	**$0.31**	n12=n09/f03
	n15	Overall avg Shut passengers per Shut trip	Pass per Shut		3.259	n15=e33
	n18	**Cost per Shuttle passenger-trip**	$		**$1.959**	n18=m15/n03
	n21	**Cost per Shut passnger mile**	$	20.3	**$0.097**	n21=n18/f03

8.4.1 Notes for the Tables

Row ID	Notes
Shading	Indicates parameters to be adjusted for various scenario investigations.
a01	Excludes travel entirely within high-density San Francisco. This will likely continue to be serviced by Muni, taxis, and on-call services. Excludes Subway (BART), Ferry, Bicycle, and Walked categories. These are unlikely to change to shuttles.
a03	From Table 8-1, these commuter counts exclude SF to SF and include SF to SM, SF to SC, SM to SM, SM to SC, and SC to SC counties. [BayAreaMetro2016a]
a09	For private road vehicles, the number of vehicle trips is the number of commuters divided by the commuters per vehicle. For busses and trolleys, the number of vehicle trips is the number of SamTrans and VTA buses and VTA light rail vehicles in the fleets, assuming every bus or trolley is active during the commute period. [511VTA2021a, SamTrans2021a] Caltrain operates on a separate right of way, so no road vehicles are included.
a12	65.2 percent of survey respondents would feel comfortable using AVs within 3-4 years after introduction. [Othman2021a]. Even in 2020, 62 per cent would ride in an AV. [Waymo202a] A 2021 survey indicated that 76 per cent of participants would use an AV. [Mouratidis2021a] In 2019, "71 percent of people are afraid to ride in fully self-driving vehicles." This study assumes that percentage will reduce significantly over 14 years. [Edmonds2019a] Assumption: 65 per cent of most commuter categories would use CalShuttle. Usage by motorcyclists and others would be much lower; assumed at 10 percent.
a18	Assumption: CalShuttle vendor algorithms will achieve an average per-shuttle passenger count of 4 per trip during commute hours.
a45	Per commute period of 5 hours (6 to 11 am, 3 to 8 pm): Data: Average Bay Area commute time is 31 minutes. [VitalSigns2018a] Average passenger wait time could be as low at 5 minutes. [Bischoff2016a] Assumption: Shuttle wait / travel time between pickups is a conservative 12 minutes. Shuttle trips per commute period: 300 minutes / (31+12) = 6.98 trips.
a48	The peak evening commute hour traffic load is 8.4 percent higher than the average over both 5-hour commute periods; this factor increases the Shuttle count to address this higher peak demand. [FHWA2014a]
a51	SamTrans bus vehicle spare ratio is 17 percent. Electric vehicles should require 50 percent less maintenance, which should translate to 50 percent fewer spare Shuttles being required. [Harto2020a, Pierlott2018a]
a63 to a75	Double single commute period counts, trips for totals for both commuter periods.

Row ID	Notes
b06, c06, d06	Percentage of trips during non-commute / Saturday / Sunday hours vs. commute periods. [FHWA2014a] Assumption: 1 passenger per Vehicle for these hours.
b09, c09, d09	Assumption: 25 percent, lower than 65 percent passenger conversions to Shuttles due to lower traffic congestion.
b12, c12, d12	Assumption: 2 passengers per Shuttle trip.
b15, c15, d15	Non-commute / Saturday / Sunday Shuttle trips would be less than morning or evening commute period Shuttle trips spread over more hours, so the Shuttle count during commute periods would be sufficient to cover these hours. Shuttle trips per Shuttle = count of (Non-commute) or (Saturday) or (Sunday) Shuttle trips / count of commute period Shuttles. Assumption: Non-commute / Saturday / Sunday Shuttle trips are distributed evenly across all available Shuttles.
f03	The average San Francisco Bay Area commute distance is 20.3 miles. This study applies that distance to all Shuttle trips. [Goldman2018a]
f06	Average deadheading add-on factors: Uber and Lyft 58%; Uber 69%; RideAustin 35%. [Fried2018a, Mellor2019a, Wenzel2019a] With strategically-located Shuttles based on commuting and non-commuting travel patterns, deadheading should reduce. Assumption: This study adds 50% miles per trip for deadheading.
f12	Assumption: This study adds a 50 miles-per-day mileage range margin.
f15	EV batteries should operate at between 10 percent and 80 percent battery capacity, or 70 percent usable capacity; target Shuttle range per charge = nominal range / 70 percent. [Dickson2021a]
f16	On average at 60 mph, a human-driven EV draws 20.76 kW (0.346 kWh per mile * 60 miles in one hour.) On-board AI computer processing can draw up to 2.5kW for a prototype Level 5 vehicle, but will reduce to perhaps as low as 1kW. A conservative estimate for AI processing reduces range by as much as 12 percent (2.5/2076) [Rajashekara2024c, Zargary2023k]
f18	This range calculation is an engineering tradeoff across: a) maximizing the range to reduce the count of daily charging sessions; b) maximizing the range to enable longer Shuttle trips outside the Bay Area; and c) minimizing the onboard battery storage to minimize per-Shuttle capital equipment cost.

Row ID	Notes
h06	Cost addition estimates for full level 5 autonomous vehicle sensors and other equipment range from $9,800 through $23,950 to $50,000 per vehicle initially but could reduce to as low as $1,000 to $2,000 over time. [Faggella2020a, Keeney2017a, Shaheen2018a, Wadud2017a] Two recent studies predict robotaxti prices to drop to $28,000 by 2030. [Templeton2024h, Hamlin2025f] Assumption: $40,000 per vehicle, a conservative estimate that exceeds anticipated costs at economies of scale for autonomous sensors and computer systems,
h09	By 2030 or sooner, electric vehicle batteries could last up to 1.2 million miles and 16 years. The Cruise Origin should have a lifespan of 1 million miles. [Priddle2020a, Ramirez2020a] Assumption: Each Shuttle and its battery will both be operational for 10 years.
i03	Total charging sessions needed = Shuttles needed during weekday commute hours * number of charging sessions per shuttle per weekday.
i05	Each charging session should be 20 minutes or (even) much less. Assumption: 2 charging sessions per hour x 24 hours.
i06	To maximize battery life, batteries should be kept at 80 percent full or less. Fast charging stations can fill an EV battery to 80 percent full in less than 30 minutes, or 2 charging sessions per hour * 24 hours per day = 48 per day per charger. The charger counts to support weekday commuter periods is sufficient to also support the fewer Shuttle trips over more hours during non-commute weekdays, Saturdays, and Sundays. Total chargers needed = Total charging sessions / charging sessions per day.
i09	Assumption: $80,000 per charger port. [Momentum2025c] Assumption: Adding an automatic connection between a charger and a Shuttle would add $1,000 per charging station, included in the $80,000 price. Assumption: Hydrogen chargers, if included, will cost about the same as electric chargers.
i12	One large charging station will be located at existing SamTrans and VTA yards: SamTrans North and South Yards (2), and VTA Palo Alto, Light Rail, and Chaboya Division (3). Other chargers are distributed across existing county and city parking lots. Assumption: 1 large charging station at each of 5 existing SamTrans and VTA yards.
i15	Each charging station might require its own new electrical substation. Assumption: Each electrical substation will cost $11 million. [Wall2009a]

Row ID	Notes
i21, j09	kWh per mile efficiency ranges from 0.260, 0.309 and 0.354 (2021) to 0.54 (2012). [Ecocost2021a, Hogeveen2021b, VanHire2021a] Lucid Air has achieved 0.271 kWh per mile (4.6 miles / kWh) and a 500-mile range. Other automakers will likely follow suit. [Ulrich2021a] Assumption: kWh per mile in 2030 will be better than the worst in 2021, so a conservative 0.354 is applied.
i24	Assumption: Maintain 12 hours 0.50 day) of backup battery storage.
i27	Assumption: Battery storage cost will be no higher than $65 per kWh. [Najman2024k]
i33	Assumption: No land costs because CalShuttle charging and maintenance facilities will use existing Muni (if needed), SamTrans, VTA facilities plus county and city government parking lots.
i36	Charging station total cost = chargers+substations+battery storage
i39	A charging station lifespan will likely be 10 years. [GNY2021a]
j09	Wireless charging should be nearly as efficient as cable charging, so no factor is applied for any potential difference. [Emilio2021a]
j12	The average commercial electricity rate in both San Mateo and Santa Clara Counties is $0.1408. [ElectricityLocal2021a]
k06, l06	Bank business loan rates range from 2 percent to 13 percent. [DeNicola2020a] Assumption: This study applies a loan rate of 7 percent for expected Shuttle and charging station lifespan of 10 years.
k09, k12, k15	AAA reports annual per vehicle cost of: insurance $1,202; license, registration, fees $851; maintenance, repair, tires per mile $0.09. Electric vehicles save 50 percent on maintenance and repairs. [AAA2020a, Harto2020a] Assumption: This study applies the AAA insurance and license / registration / taxes values. This does not include any special taxes and fees that might be levied on electric vehicles, which are to be determined by the State legislature. Assumption: This study applies a $0.06 value for maintenance, repair, and tires; maintenance and repair costs should be 50 percent less, but tire wear should be the same.
l09	Charging station maintenance per year should be $400 per charger. [DOE2021a]
m06	Costs for CalShuttle to providing charging stations sites, including: charging stations, grid connectivity, backup energy storage, maintenance garages, site security. Also monitoring Shuttle vendor operations. This is somewhat comparable to but much less extensive than activities and services provided by airports to commercial air carriers, covered by airport landing fees. Airport landing fees are 2.5 percent of airline operating expenses. [A4A2021a] Assumption: This study applies a 3 percent assessment to Shuttle vendors' other operating expenses to cover CalShuttle administration.

Row ID	Notes
m12	Gross margins for industries somewhat similar to CalShuttle vendor-provided shuttles include: 5 to 10 percent for rental car companies (net income); Air Transport 5.38 percent, Auto & Truck 9.04 percent, Transportation 19.91 percent; Avis 24.8 percent. [Cynthia 2021a, Damodaran2021a, WSJ2020a] The formula for the resulting cost addition is: gross margin addition = total annual cost of services / (1 - gross margin percentage) - tornal annual cost of services. Assumption: This study applies a gross margin value of 15 percent. Rental car companies do not pay for fuel (gasoline); renters pay for that. For CalShuttle Shuttles, the Shuttle vendors will pay for the fuel (electricity or hydrogen), increasing the cost-of-goods-sold, thereby reducing the gross margin.
n12	This bottom-up calculation of $0.32 per Shuttle mile matches well with other estimates of $0.37 and $0.30 to $0.50 per mile. [Keeney2017a, Othman2021a, Sperling2018a, Tran2025e]

8.5 VTA BART Extension

8.5.1 Conclusion: 55,000 daily riders served by 1500 or fewer shuttles

CalShuttle would replace the VTA BART Extension service with 1,000 to 1,500 shuttles. These commuters are already included in the Section 8.1 analysis because, presumably, these riders are already commuting within Santa Clara county by some means. [VTA2021a]

Table 8-5. CalShuttle Replacement for VTA BART Extension

	VTA BART Extension Shuttles Replacement			Early Operation			Later Operation			
		Unit	Factor	Item	(Sub) Totals	Factor	Item	(Sub) Totals	Formula	Source or Notes
	VTA BART Extension Projected Riders									
	All 4 San Jose / Santa Clara BART station riders									
	Both directions									
a	Total, all-day	Commuters		55,000			55,000		a	[VTA2021a]
b	Total, morning or evening	Commuters	2	27,500		2	27,500		b = a / X	calc, 1
c	Conversion to CalShuttle	Commuters	90.00%	24,750		95.00%	26,125		c = b*X	calc, 2
d	Commuter per Shuttle loading	Shuttles	4		**6,188**	5		**5,225**	d = c/X	calc, 2
e	Continuing in other Vehicles	Commuters			**2,750**			**1,375**	e = b-c	calc
f	Total Commuter Vehicles trips				**8,938**			**6,600**	f = d+e	calc
g	Total Shuttles needed commute		4		**1,547**	5		**1,045**	g = d/X	calc, 2

8.5.2 Notes

1 The VTA projection of 55,000 daily riders is divided in two: midnight to noon and noon to midnight. Then, to provide a very conservative estimate for commuting riders, the entire noon-to-midnight ridership is allocated to commuters.

2 Two estimates are provided:
Early operation after some acceptance has been achieved.
Later operation after widespread acceptance has been achieved.
This study presumes high adoption rate because these projected riders are already committed to public transit.

	Early Operation	Later Operation
% Change to Shuttles - adoption acceptance.	90%	95%
Commuter/Shuttle loading - average number of passengers per shuttle during commute hours.	4	5
Each Shuttle trips per commute - average number of trips per shuttle during each 4-hour commute period.	4	5

9 Terminology and References

9.1 Terminology

ACS	Automated connected shuttle
AS	Automated shuttle
AV	Autonomous vehicle
CAV	Connected autonomous vehicle
CSAV	Connected shared autonomous vehicle
ITS	Intelligent transportation system
MAAS	Mobility as a service
Microtransit	Demand responsive transport vehicle for hire
SAV	Shared autonomous vehicle
TAAS	Transit as a service

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Table 9-1. Commuting Patterns for SF, SM, SC Counties, 2016.

Res_Geo_Short	Work_Geo_Short	Totals	Drove alone	2-person carpool	3-person carpool	4-person carpool	5-or-6-person carpool	7-or-more-person carpool	Bus	Streetcar or trolley	Railroad	Taxi	Motorcycle	Other
San Francisco	San Francisco	233,145	96,640	17,805	3,820	1,385	515	335	91,200	10,145	1,110	3,015	3,740	3,435
San Mateo	San Francisco	70,355	49,075	7,310	1,635	515	185	85	5,310	230	4,985	10	325	690
Santa Clara	San Francisco	14,650	7,455	975	140	55	25	35	720	60	5,065	15	15	90
San Francisco	San Mateo	47,440	34,880	3,660	745	215	170	135	4,675	230	1,735	135	305	555
San Mateo	San Mateo	190,210	157,070	17,100	3,305	1,295	585	250	6,595	80	1,445	105	480	1,900
Santa Clara	San Mateo	45,675	35,380	4,095	780	235	180	285	1,335	35	2,515	10	140	685
San Francisco	Santa Clara	26,750	12,605	1,540	250	95	20	140	6,845	175	4,045	35	95	905
San Mateo	Santa Clara	58,640	47,855	4,910	750	415	100	65	1,410	10	2,445	45	215	420
Santa Clara	Santa Clara	714,140	598,310	64,550	10,760	3,225	1,985	815	19,105	1,225	4,790	1,075	3,020	5,280
Total, all		**1,401,005**	1,039,270	121,945	22,185	7,435	3,765	2,145	137,195	12,190	28,135	4,445	8,335	13,960
Total, without SF to SF		**1,167,860**	942,630	104,140	18,365	6,050	3,250	1,810	45,995	2,045	27,025	1,430	4,595	10,525

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Table 9-2. Vehicle Counts by County; reductions by 1 per 50% of households (Mike Forster)

Item	**San Francisco County, California**	**San Mateo County, California**	**Santa Clara County, California**	Calculation Notes
1 vehicle available	152,418	77,405	180,173	a3
1 vehicle total all 3 counties			409,996	b = sum(a3)
% Reduce family vehicle count to 0			25%	c (assumption)
Number of vehicles reduced			**102,499**	d = b x c
2 vehicles available	67,285	105,675	259,249	e3
3 vehicles available	21,483	41,919	105,936	f3
4 or more vehicles available	6,328	24,941	61,749	g3
2 or more vehicles by county	95,096	172,535	426,934	h3 (sums)
2 or more vehicles all 3 counties			694,565	I = sum (h3)
% Reduce family vehicle count by 1			50%	j (assumption)
Number of vehicles reduced			**347,283**	k = I x j
Total vehicles reduced 3 counties			**449,782**	l = d+k

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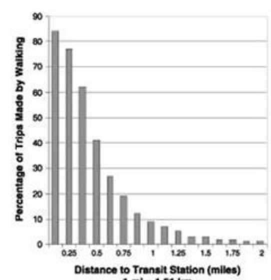

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- Middle of the day: Maximum trip duration: 29 minutes (mean).
- Nighttime: 16 percent (with qualifications).
- Nighttime: Maximum trip duration: 34 minutes (mean).
- Acceptable cost per mile, response time under: 1 minute $0.75; 2 minutes $0.71; 5 minutes: $0.64.
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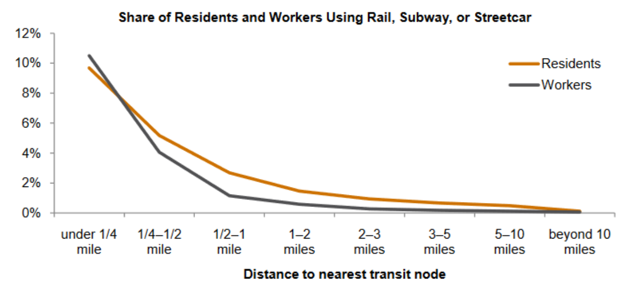

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Safety: +40% to +90% increase in safety
Capacity: 0% to +45% increase in roadway capacity
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- 65.2 percent would feel comfortable using AVs within 3-4 years after introduction.

> A US survey by The Motional Consumer Mobility of 1003 consumers regarding AVs:
- 86 percent will travel in AV.
- 66 percent will consider using AVs regularly.
- 82 percent believe that AVs are the way to the future.

> AVs in general and shared AVs especially reduce costs.
- Autonomous taxis operating costs could reduce by 30 to 50 cents per mile and/or 60 to 75 percent.
- Figure 7: Shared AVs have lowest per-mile cost at $0.37 per mile.
- Ann Arbor shared AV simulation with customer waiting time of 2 minutes or less showed a 9 percent cost reduction due to lower ownership cost, operating expenses, parking fees, and the value of time gained.
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> One study "… noted that if AVs allow disabled individuals to make the same length and number of car trips, their vehicle-miles traveled (VMT) would probably increase by more than 50 percent."
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- Vehicle maintenance costs per service mile: $2.74.
- Vehicle spare ratio: 17 percent.
- Administrative costs: 32 percent of total operating costs.

- Maintenance costs: 19 percent of total operating costs.

Functional Performance Inputs - Systemwide (All Modes)

Data Item	FY2015	FY2016	FY2017	Source
Total Operating Costs	$121,179,721	$129,537,320	$133,146,565	NTD F-40
Administrative Costs	$35,295,159	$39,107,637	$43,015,960	NTD F-40
Vehicle Service Hours	702,074	731,625	844,038	NTD S-10 (all modes)
Marketing Costs	$2,891,500	$3,174,000	$4,101,073	SamTrans Budget
Unlinked Passenger Trips	13,796,204	13,530,765	12,550,962	NTD S-10 (all modes)
Farebox Revenue (All Modes)	$18,816,424	$18,078,032	$17,040,333	NTD F-10

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10 Version History

Date	Version	Notes
19 February 2022	1.0	First edition.
1 March 2022	1.1	Expanded 2.8 to address work-from-home, other 2.x edits. Expanded 3.11 to address bicycles, reduced 3.9, eliminated 3.14. Added [Jaffe2015a, Thompson2022a]. Minor editing corrections.
6 March 2022	1.2	Expanded 6.2 and 6.5. Added [Jackson2019a], [Othman2022a]. Minor reformatting.
13 April 2022	1.3	Expanded 5.3 to address transit station proximity, with references García-Palomares2018a, FHA2022a, Kolka2011a, MWCOG2016a, Wiseman2019a]. Added [Othman2022b]. Reworded 3.11 title for better formatting. Minor reformatting and corrections.
16 January 2023	2.2	Moved some comments to different sections. Added comments from new references. Minor reformatting and corrections.
18 October 2023	3.3	Gathered cost avoidance saving and questions to section 7. Added and noted additional references. Minor reformatting and corrections.
28 January 2024	3.4	New references to studies, Bay Area initiatives added.
7 June 2025	3.5	Updated some analysis factors from recent publications. Added references from recent publications. Some reformatting.

