

CalShuttle: On-Demand, Point-to-Point, Fast, Safe Shared Autonomous Vehicles

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CalShuttle - The Future of Bay Area Transit



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), and mobility as a service (MAAS).

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, 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 target to average 4 riders per trip during commute hours and 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]

Platooning of vehicles will enable more vehicle-handling capacity on existing highways due to smaller spacing between vehicles, and will reduce traffic instabilities and enhance traffic throughput. [Martinez-Diaz2021a]

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 as Vehicles do in the 2020s. 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 to their destinations.

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 and operated. 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:

- 31,444 Shuttles will reduce commute periods vehicles on the road by 46% or 498,000 vehicles and therefore will reduce traffic congestion.
 - This ratio of 1 Shuttle to 15.8 vehicles reduced aligns with ratios of 5 to 20 from other studies. [Fagnant2014a, Hogeveen2021a, Manders2020e, Othman2022b, Pisarov2021a, Shaheen2020a]
- Studies have showed that replacing all replacing all cars 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 in big city downtown areas. [Gora2016a, Park 2021a, Pizarov2021a, 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 robo-taxis, a 33% acceptance rate of current car users, and 10% peak demand decrease would eliminate traffic congestion (page 5).
- 6-seater robo-taxi 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 family 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]

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

Household automobile insurance premium costs will reduce due to the reductions in the number of accidents and in the 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 reduce. [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 and pedestrian 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. Indirect health care costs across society would likely reduce significantly. A Waymo Automated Driving System (ADS) study shows already a lower rate of both the frequency and severity of collisions as compared to the comparable National Highway Traffic Safety Administration's comparable incidents. [Golomb2021a, Gora2016a, Keeney2017a, Othman2022a, Othman2022b, Pizarov2021a, Singh2015a, Smith2013a, Victor2023, Weijermars2022g]

3.6 Improves mobility for our older and disabled residents.

Shuttles will provide more travel for older 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. Public transit is often a critical lifeline for seniors and people with disabilities. Microtransit optimizes typically inefficient paratransit options, creating real-time bookings, higher quality service, and reducing trip costs with more efficient and equitable shared rides. [Othman 2022a, Othman2022b, Perrine2018a, Via2020c]

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 more friendly, greener and livable place." [Horl2017a]

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. [Keeney2017a, Manders2020e, Othman2022a, Othman2022b, Pizarov2021a, Shaheen2018a]

Many street side parking spaces will be converted to: protected bike lanes, enabling bicycles, scooters, and skateboards to become viable alternatives; and even to pedestrian spaces, "reclaiming street space for people". [Chambard2023e, Jaffe2015a]

Nearly all shuttles will be active during the rush period, 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. Where demand and density are highest, shuttles will park in lots or garages, but can be packed more densely with a last in-first out algorithm. Shuttles will also be at recharging stations during the off hours. [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. [Othman2022a, Othman2022b, Perrine2018a, Shaheen2020a, Waymo2020a]

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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 an 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 to provide space 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 125-mph California High Speed Rail trains: 40 crossings at up to \$1M per crossing.

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.

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

- 31,444 CalShuttle-administered, private vendor-operated Shuttles.
- 432.3 million annual passenger trips.
- 143.5 million annual Shuttle trips.
- 20.3 mile average Shuttle trip distance.
- 3.4 average Shuttle passenger load per trip: 4 during commute periods, fewer other times.
- \$2.30 fare per Shuttle passenger, which equals \$0.11 per passenger mile for a 20.3 mile trip.

A \$2.30 fare is similar to an acceptable fare of \$2 reported in one study. [Shaheen2020a]

\$0.11 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]. \$0.11 per passenger-trip 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]

\$0.11 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 Francisco, San Mateo, and Santa Clara Counties families 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.

"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 2023 ... but they will be.

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, PaloAlto2023a, 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. 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. 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 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." [Dans20221]

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

- Autonomous taxi, rideshare, and delivery services
 - Waymo's driverless robotaxis are operational in Phoenix, Arizona suburbs. [Duffy2021a]
 - 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]

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- 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 AV pilot in San Francisco, December 2022. [Griner2022i]
- Cruise AV pilot in Austin, December 2022. [Dow2022i]
- "Lyft ... will test self-driving taxi rides in Las Vegas ... starting in 2023." [Akers2021a, Davalos2021a, IntelTransport2021a]
- Waymo to start operating autonomous vehicles in Los Angeles in the coming months. [Waymo2022j]
- Bishop Ranch business park driverless autonomous shuttles. [Wittner2023d]
- San Jose considering a fleet of 200 robotic shuttles San Jose Airport and downtown San Jose, using a dedicated new guideway. [Greschler2023d]
- Waymo approved to expand driverless taxi services in San Mateo County and as far south as Sunnyvale. [Baron2024a]
- On-demand transit services (not yet autonomous)
 - Richmond, CA launched an on-demand transit service in April 2022. [Via2022d]
 - SamTrans door-to-door on-demand pilot in East Palo Alto and Half Moon Bay [PADailyPost2023a]
 - Palo Alto Link on-demand rideshare service. [Sheyner2023b]
- Manufacturer developments including trucks
 - "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]
 - The truck driver shortage will drive the deployment of autonomous trucks. [Kovacevich2022a]
 - Ford enhances Advanced Driver Assistance Systems (ADAS) in Mustang Mach-E in fall of 2022. [Hamblen2022i]
 - China's Jidu Automotive will marking a self-driving car in 2023 for about \$55,000. [Dans2022i]
- Government initiatives
 - San Mateo County is looking ahead 5, 10, 20 years and considering autonomous vehicles including shuttles for public and private transportation. [Bowning2021a]
 - The National Academies have provided a framework for states and localities to evaluate AV safety. [BTSCR2022a]
 - The San Francisco Bay Area Metropolitan Transit Commission (MTC) is sponsoring a "technical assistance grant program to fund SAV technology pilot/deployment projects." [MTC2023b]
 - 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]

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 AVs comprise a 30% share of light vehicle sales by 2030 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." Trucking, 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 further 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 privacy of 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 were 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.

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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 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

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 Francisco is excluded. The assumption is that travel entirely within San Francisco will continue to be serviced by San Francisco Muni buses and light rail / trolleys, taxis, and other existing means of transportation.

8.2 Legend

Term	Definition
Chargers	An electric or hydrogen for one Shuttle at a time
Charging stations	A group of charging stations 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." [Conner-Simons2016a]
- "95 percent of demand would be covered by just 2,000 ten-person vehicles, compared to the nearly 14,000 taxis that currently operate in New York City. [Conner-Simons2016a]
- "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 130,000 vehicles could replace 1.1 commuting private cars with shorter wait times. [Bischoff2016a]
- Extrapolating from one study, 31,444 Shuttles would require only 1168 chargers, much less than the 1965 estimated in this study; i.e., 1965 chargers would be more than enough. [Dlugosch2022g]

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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

Table 7-1. Counts of Pass Trips and Shuttles	Unit	(Factor)	Totals	Formulas	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
a01	A: Weekday Commuter Conversions to Shuttles															
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						
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	Pass 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, Shuts needed	Shuttles	7	a45=a42/F	26,891											
a48	% Increase for peak hour	Shuttles	8.4%	a48=a45*F	2,267											
a51	% Spare Shuttle ratio	Shuttles	8.5%	a51=a45*F	2,286											
a54	Total Shuttles needed	Shuttles	31,444	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	a63=a15*F	1,501,586											
a66	Conventional trips	Vehicle trips	2	a66=a09*F	2,042,240											
a69	New total Vehicle trips	Vehicle trips	2	a69=a33*F	1,106,195											
a72	Change Conv to Vehicle trips	Vehicle trips		a72=a69-a66	-936,045											
a75	% Change Conv to Vehicle trips	%			-45.8%											
a78	Total Shuttle trips	Shuttle trips	2	a75=a24*F	375,397											
a81	Trips per Shuttle	Shuttle trips	2	a78=a45(F)*F	14											
b01	B: Weekday Non-Commute Conversions to Shuttles, and 5-Day Week Totals															
b03	Both periods Conventional trips	Conv trips		a66	2,042,240											
b06	% Non-Commute / Commute trips	Conv pass trips	40%	b06=b03*F	816,896											
b09	% passengers Change to Shuttles	Shut pass trips	20%	b09=b06*F	163,379											
b12	Pass per Shuttle, Shuttle trips	Shuttle trips	2	b12=b09/F	81,690											
b15	Weekday Shuttle trips per Shuttle	Shuttle trips		b15=b12/a54	2.6											
b18	Typical max weekday trips per Shut	Shuttle trips		b18=a78+b15	16.6											
b21	Typical max 5-day trips per Shuttle	Shuttle trips	5	b21=b18*F	82.8											
b24	Weekday Shuttle trips	Shuttle trips		b24=a78+b12	457,086											
b27	5-day Shuttle trips	Shuttle trips	5	b27=b24*F	2,285,430											
b30	Weekday passengers	Shut pass trips		b30=a63+b09	1,664,965											
b33	5-day Shuttle passengers	Shut pass trips	5	b33=b30*F	8,324,826											
c01	C: Saturday Conversions to Shuttles															
c03	Weekday Veh trips	Veh trips		c03=b03+b06	2,859,135											
c06	% Saturday vs. Weekday trips	Veh pass trips	93%	c06=c03*F	2,658,996											
c09	% passengers change to Shuttles	Shut pass trips	20%	c09=c06*F	531,799											
c12	Pass per Shuttle, Shuttle trips	Shuttle trips	2	c12=c09/F	265,900											
c15	Saturday trips per Shuttle	Shuttle trips		c15=c12/a54	8.5											
d01	D: Sunday Conversions to Shuttles															
d03	Weekday Trips	Veh trips		c03	2,859,135											
d06	% Sunday / Weekday trips	Veh pass trips	73%	d06=d03*F	2,087,169											
d09	% passengers change to Shuttles	Shut pass trips	20%	d09=d06*F	417,434											
d12	Pass per Shuttle, Shuttle trips	Shuttle trips	2	d12=d09/F	208,717											
d15	Sunday trips per Shuttle	Shuttle trips		d15=d12/a54	6.6											
e01	E: Weekly and Annual Totals for Shuttles															
e06	5-day Shuttle trips	Shuttle trips		e06=b27	2,285,430											
e09	Saturday Shuttle trips	Shuttle trips		e09=d12	265,900											
e12	Sunday Shuttle trips	Shuttle trips		e12=d12	208,717											
e15	Total full week Shuttle trips	Shuttle trips		e15=e06+e09+e12	2,760,047											
e18	Total annual Shuttle trips	Shuttle trips	52	e18=e15*F	143,522,440											
e21	Average weekly trips per Shuttle	Shuttle trips		e21=b21+c15+d15	97.9											
e24	Average annual trips per Shuttle	Shuttle trips	52	e24=e30*F	5,090											
e27	Total weekly Shuttle passengers	Shut pass trips		e27=b33+c09+d09	9,274,059											
e30	Total annual Shuttle passengers	Shut pass trips	52	e30=e18*F	482,251,059											

Table 8-2. Shuttle Miles

Table 7-2: 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	16.6	504	f09=f06*b18
f12	Shut range margin, nominal range	miles	50	554	f12=f09+F
f15	% charging target, daily range	miles	70%	792	f15=f12/F
f18	Weekday charges, target range	miles	3	264	f18=f15/F
g01	H: Annual Mileage Total and Per Shuttle				
g03	Total annual Shuttle trips	Shuttle trips		143,522,440	g03=e18
g06	Miles - per trip, total annual	miles	30.5	4,370,258,285	g06=h03*f06
g09	Total Shuttles	Shuttles		31,444	g09=a54
g12	Annual miles per Shuttle	miles		138,986	g12=g06/g09

Table 8-3. Capital Costs

Table 7-3. Capital Costs: Shuttles, Chargers		Unit	(F)actor	Totals	Formulas
h01	F: Shuttles Capital Costs				
h03	Total Shuttles needed	Shuttles		31,444	h03=a54
h06	Shuttles capital cost each, total	\$Million	\$80,000	\$2,516	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	94,332	i03=h03*F
i06	Daily charger sessions, total chargers	chargers	48	1,965	i06=i03/F
i09	Chargers cost, each and total	\$Million	\$7,000	\$14	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		17,425,918	i18=a54*f12
i21	kWh - per mile, per day, all Shuttles	kWh	0.35	6,168,775	i21=i18*F
i24	Days, total kWh storage	kWh	0.50	3,084,387	i24=i21*F
i27	Battery storage cost - per kWh, total	\$Million	\$100	\$308	i27=i24*F
i30	Charging station costs, total	\$Million		\$377	i30=i09+i15+i27
i33	Charging stations land costs	\$Million	\$0	\$0	i12
i36	Total Capital Costs	\$Million		\$2,893	i36=h06+i30
i39	Charging stations operational life	Years	10		i39=i15

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Table 8-4. Costs, Annual and Per Passenger

Table 7-4: Costs: Annual Total, Per Passenger		<u>Unit</u>	<u>(F)actor</u>	<u>Totals</u>	<u>Formulas</u>
j01	<u>J: Electricity</u>				
j06	Total annual Shuttle miles	miles	30.5	4,370,258,285	j06=j03*F
j09	kWh - per mile, total for all shuttles	kWh	0.35	1,547,071,433	j09=j06*i21(F)
j12	Annual total electricity cost all Shuttles	\$Million	\$0.14	\$218	j12=j09*j12(F)
k01	<u>K: Annual Costs, per Shuttle and all Shuttles</u>				
k06	Annual amortized financing	\$	5%	\$10,182	k06 (see Notes)
k09	Annual insurance	\$		\$1,202	k09 (see Notes)
k12	License, registration, taxes	\$		\$851	k12 (see Notes)
k15	Maintenance, repair, tires per mile	\$	\$0.06	\$8,339	k15=h12*F
k18	Total annual expenses per Shuttle	\$		\$20,574	k18=sum(k06...k15)
k21	Total Shuttles needed	Shuttles		31,444	k21=a54
k24	Total annual expenses, all Shuttles	\$Million		\$647	k24=k18+k21
l01	<u>L: Charging Station Expenses (all Chargers)</u>				
l06	Annual amortized financing	\$Million	5%	\$48	l06 (see Notes)
l09	Annual maintenance, per Charger and all C	\$Million	\$400	\$1	l09=g12*F
l12	Total annual Chargers expenses	\$Million		\$49	l12=l06+l06
m01	<u>M: Overhead, Profit Margin, CalShuttle</u>				
m03	Subtotal elec., expenses, stations	\$Million		\$914	m03=j12+k24+l12
m06	CalShuttle admin. overhead addition	\$Million	3%	\$27	m06=m03*F
m09	Subtotal vendor, CalShuttle admin	\$Million		\$941	m09=m03+m06
m12	Vendor gross margin addition	\$Million	15%	\$166	m12 (see Notes)
m15	Total annual vendor costs	\$Million		\$1,107	m15=m09+m12
n01	<u>N: Cost per passenger trip</u>				
n03	Total annual Shuttle trips	Shuttle trips		143,522,440	n03=e18
n09	Cost per Commuter-length Shut trip	\$		\$7.71	n09=m15/n03
n12	Length, cost per Shuttle trip mile	\$	20.3	\$0.38	n12=n09/f03
n15	Total annual Shuttle passenger-trip	Shut pass-trips		482,251,059	n03=e21
n18	Cost per Shuttle passenger-trip	\$		\$2.30	n06=m15/n03
n21	Cost per Shut pass-trip mile	\$	20.3	\$0.11	n09=n06/f03
n24	Average Shuttle passenger loading	Shut passengers		3.4	n24=n15/n03

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 have few commuters, and 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]
a06	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, set at 10 percent.
a18	Assumption: CalShuttle shuttles will achieve an average per-shuttle passenger count of 4 per trip during commute hours.
a24	Assumption: All public transit passengers (Bus, VTA Light Rail, Caltrain) move to single-passenger Conventional commuting.
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] Assumption: Shuttle wait / travel time between pickups is 12 minutes. Shuttle trips per commute period: 300 minutes / (21+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.

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Row ID	Notes
b06, c06, d06	<p>Percentage of trips during non-commute / Saturday / Sunday hours vs. commute periods. [FHWA2014a]</p> <p>Assumption: 1 passenger per Vehicle for these hours.</p>
b09, c09, d09	<p>Assumption: Much lower than 65 percent passenger conversions to Shuttles due to lower traffic congestion.</p>
b12, c12, d12	<p>Assumption: 2 passengers per Shuttle trip.</p>
b15, c15, d15	<p>Non-commute / Saturday / Sunday Shuttle trips are less than morning or evening commute period Shuttle trips spread over more hours, so the Shuttle count during commute periods is sufficient to cover these hours.</p> <p>Shuttle trips per Shuttle = count of (Non-commute) or (Saturday) or (Sunday) Shuttle trips / count of commute period Shuttles.</p> <p>Assumption: Non-commute / Saturday / Sunday Shuttle trips are distributed evenly across all available Shuttles.</p>
f03	<p>The average San Francisco Bay Area commute distance is 20.3 miles. This study applies that distance to all Shuttle trips. [Goldman2018a]</p>
f06	<p>Average deadheading add-on factors: Uber and Lyft 58%; Uber 69%; RideAustin 35%. [Fried2018a, Mellor2019a, Wenzel2019a]</p> <p>With strategically-located Shuttles based on commuting and non-commuting travel patterns, deadheading should reduce.</p> <p>Assumption: This study adds 50% miles per trip for deadheading.</p>
f12	<p>Assumption: This study adds a per day mileage range margin.</p>
f15	<p>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]</p>
f18	<p>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.</p>
h06	<p>Cost addition estimates for full level 5 autonomous vehicle operation 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]</p> <p>Assumption: \$25,000 additional per vehicle cost for full autonomous operation by 2030 plus \$10,000 for upgrades and other fees, total \$35,000. This conservative estimate far exceeds anticipated costs at economies of scale for autonomous sensors and computer systems, which could fall to as low as \$1,000 to \$2,000 per vehicle. [Keeney2017a]</p> <p>The 2022 Ford E-Transit cargo van MSRP starts at \$45,000; adding \$35,000 totals \$80,000 capital equipment cost per Shuttle.</p>

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Row ID	Notes
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.
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	The 2021 cost for the purchase and installation of a (manual) single Level II EV charger is \$6,000. Assumption: Adding an automatic connection between a charger and a Shuttle would add \$1,000 per charging station. Assumption: Hydrogen chargers, if included, 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]
i21, j09	kWh per mile range 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 at least near the best in 2021, so 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 \$100 per kWh. [Kharaya2021a]
i33	Assumption: No land costs because CalShuttle charging and maintenance facilities will make use of existing Muni (if needed), SamTrans, and VTA bus and light-rail 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]

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Row ID	Notes
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 5 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.
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) - total 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	\$0.38 per Shuttle mile matches well with other estimates of \$0.37 per mile. [Keeney2017a, Othman2021a, Sperlign2018a]

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

- 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.
- 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

9.2 References

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> Santa Clara County VTA operates 520+ buses and 50 light rail cars.

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> Airport landing fees are 2.5 percent of operating expenses.

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[Abe2021a] Ryosuke Abe, Preferences of urban rail users for first- and last-mile autonomous vehicles: Price and service elasticities of demand in a multimodal environment, 5 April 2021.

> "AVs have diverse substitution patterns with existing modes. Riding in AV services is more likely to be a substitute for riding on buses/in slower modes of transit for all travel purposes, and for driving cars, particularly for leisure trips, but less likely for cycling and walking, particularly for work trips. The AV wait time elasticities might vary according to the waiting environment and conditions. The results also suggest that AVs may particularly benefit those who currently have restrictions in accessing transit."

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[Adams2020a] Eric Adams, Why we're still years away from having self-driving cars, Vox Recode, 25 September 2020.

> Autonomous car operation still has technical issues to resolve. 5G will enable many useful features: "Though the cars will by and large be able to operate without connectivity, having a more robust, faster, higher-bandwidth wireless data system will significantly boost the autonomous vehicle network's capabilities. Cities will be able to optimize traffic patterns, cars will know ahead of time what the traffic signals will be at every intersection, and vehicles will communicate with each other to ease everything from lane changes to routing strategies based on congestion or weather. ... Researchers have already demonstrated the systems' abilities to precisely coordinate autonomous vehicles threading their way past each other with millisecond timing, thanks to all the vehicles automatically gauging their relative positions and deciding who goes where."

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> Federal officials now estimate the extension cost will be \$9.148 billion.

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[Bansal2017a] Prateek Bansal and Kara M. Kockelman, Forecasting Americans' Long-Term Adoption of Connected and Autonomous Vehicle Technology, University of Texas, 2017.

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https://www.cae.utexas.edu/prof/kockelman/public_html/trb16cavtechadoption.pdf

[Bagli2022k] Hannah Bagli et al, Automated Vehicles: Use, Share, Own? Young Adults' Perceptions of Automated Vehicles, Sage Journals, Transportation Research Record, November 2022, Vol. 2676, pp. 263-273.

> Per a 2022 survey, younger adults under the age of 35 are ambivalent towards AVs, with mostly between 40 and 50 percent extremely or somewhat comfortable with riding in an AV for everyday travel or relying on shared CAVs, or definitely or probably wanting to own a CAV.

<https://journals.sagepub.com/doi/10.1177/03611981221092382>

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> Data on the number of commuters within and across county boundaries by transportation type - automobile, bus, streetcar, railroad, taxis, etc.

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Data source: U.S. Census Transportation Planning Package, Table A302103 5-Year Average (2012-2016)

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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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The duration of a grade separation project, from initial planning to construction close out, varies greatly depending on a few key factors: the size of grade separation, funding availability, community acceptance, right-of-way acquisition, and utility relocation needed."

<https://www.caltrain.com/ccs/faqs>

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

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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> "... companies like GM aim to market autonomous vehicles directly to the public by around 2030."

> "... LiDAR sensors, for example, have experienced very steep reductions in price and size from 2015's "spinning KFC bucket" that cost about \$75,000 to today's \$100 the size of a soda can or even smaller."

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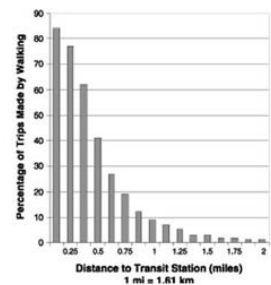
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> Figure 3-3: Hour of Day for Urban, Rural, and Recreational Sites

A manual extraction of percentages from this chart reveals that Urban (weekday) commute hours traffic from 6 to 10 am and 3 to 8 pm totals 60 percent of vehicle trips, and the remaining 16 hours totals 40 percent of vehicle trips.

> Figure 3-4: Day of the Week for Urban, Rural, and Recreational Sites (Weekend)

A manual extraction of percentages from this chart reveals that Saturday vehicle trips are 7 percent lower and Sunday 26 percent lower than the weekday average.

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> "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."

> "... passenger cars will likely be one of the last vehicle types to see widespread autonomous adoption. Long-haul trucking will probably be the first sector, followed by deliveries. When you finally do step into an AV, it will likely be a taxi or a rental car. (Rental car companies lose a lot of money every year to driver-caused accidents, so they're eager to transition to an AV fleet that is—at least in theory—less accident-prone.)"

> "That type of shift is likely decades away, if it happens at all. Even once the technology is perfected, people might not feel comfortable riding in a car without a steering wheel at first. But I believe the benefits will convince them. AVs will eventually become cheaper than regular vehicles. And if you commute by car like me, just think about how much time you waste driving."

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> Page 15: Connectivity diagram of auto giants' alliances with tech firms and mobility service providers.

> Page 37: "According to research by LexisNexis Risk Solutions, ADAS vehicles showed a 27% reduction in bodily injury claim frequency and a 19% reduction in property damage frequency."

> Page 37: More than 90 percent of new cars will have ADAS (Level 2+) features by 2030.

> Page 101: "... the controlled pace of each autonomous car could reduce traffic for an additional 20 vehicles."

> Page 101: "Reducing human reaction times and the subsequent traffic waves, can reduce total fuel consumption by up as much as 40 percent."

> Page 102: "Approximately 94% of motor vehicle accidents are caused by human error. This is an obvious area where autonomous vehicles—that see better and are always alert—can make a major difference. In 2015, the US racked-up over 4.5 million crashed with property-damage-only, 1.7 million that caused injuries, and 32,538 that caused fatalities. ... we estimate that eliminating accidents can save up to \$501 billion annually."

> Page 102: "Autonomous driving can free-up billions of additional work hours for commuters. ... In 2015, a report released by the Texas Transportation Institute (TTI) estimated that the average driver logged an additional commute 42 hours annually due to traffic jams. These figures show us that a possible \$134 billion of additional earnings could be reclaimed annually."

> Page 109: AVs go mainstream by the late 2020s, reach significant acceptance by the mid-2030s

> Page 114: "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. ... 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. As we transition to an access economy, urban consumers will increasingly favor a driverless-car booking over car ownership."

https://www.drakestar.com/wp-content/uploads/2016/09/DrakeStar_Mobility_Report-Apr_2021.pdf

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> "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 ..."

> Section 5.4. Device breakdown: "What if a communicator suddenly ceases to work? In a world without traditional cars, a disconnected vehicle shall probably leave the road, if possible, and stop. Then it becomes an obstacle that can be easily noticed by radars of other vehicles. This, however, is not optimal for passengers of this unfortunate vehicle. Perhaps, motion of a vehicle with damaged communicator should be detected and broadcast by elements of infrastructure – then a damaged car could remain a traffic participant without posing a threat to others' safety."

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> Survey results for 2588 Americans, including 1258 Texans.

> Willingness to use dynamic ride-sharing autonomous vehicles with strangers:

- Middle of the day: 62 percent for 0 minutes additional time, \$0.74 per trip-mile.

- Middle of the day: 53 percent for 5 minutes additional time, \$0.73 per trip-mile.

- 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.

> "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."

> "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 ..."

https://www.researchgate.net/publication/338313268_Modeling_Americans%27_autonomous_vehicle_preferences_A_focus_on_dynamic_ride-sharing_privacy_long-distance_mode_choices

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> Ford enhances Advanced Driver Assistance Systems (ADAS) in Mustang Mach-E in fall of 2022

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> "Research suggests that ride hailing is replacing the use of public transportation, providing plenty of benefits including low wait times and flexibility."

<https://www.masstransitmag.com/alt-mobility/shared-mobility/article/21286212/mixed-fleets-the-future-of-microtransit-and-paratransit>

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> "The potential benefits of driverless vehicles are significant. Removing the driver greatly reduces or eliminates human error as well as risks due to human fatigue, distraction, and impairment. These factors account for the loss of nearly 40,000 lives every year in the United States. But major challenges must be addressed before driverless motor vehicles will be ready and accepted by the public for widespread use."

<https://www.nationalacademies.org/news/2021/09/driverless-motor-vehicles-not-yet-ready-for-prime-time>

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> "...drivers of electric vehicles are saving an average of 50% on maintenance and repair over the life of a vehicle compared to owners of gas-powered vehicles."

https://advocacy.consumerreports.org/press_release/electric-vehicle-owners-spending-half-as-much-on-maintenance-compared-to-gas-powered-vehicle-owners-finds-new-cr-analysis/

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> Figure 2: Number of conventional vehicles replaced by shared autonomous electric vehicles per previous modeling studies: 7, 8, 9, 10, 10, 20.

https://www.researchgate.net/publication/351676521_Quantifying_the_Fleet_Composition_at_Full_Adoption_of_Shared_Autonomous_Electric_Vehicles_An_Agent-based_Approach

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> Electric SAV characteristics assumed by this study: passengers, top speed, weight, energy use:

- Single: 1, 130 km/h, 450 kg, 40 Wh/km.

- Multiple: 1 to 10, 160 km/h, 1600 kg, 160 Wh/km [96 mph, 3520 lbs, 0.26 Wh/mi]

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> "Future predictions foresee a considerable increase of the effective road capacity through intelligent and interconnected vehicles. 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 a more friendly, greener and liveable place. ... On the flip-side, more vehicles might be observed on the roads if autonomous vehicles [AVs] get so comfortable, cheap and available that aggregated transit forms such as busses or trains become obsolete."

> Figure 2 and Table 1: With a large fleet size, about 21 per cent of riders choose AV pool sharing with a maximum of 4 passengers and average wait time of 6 minutes during peak hours and 93 per cent with an average wait time of 2 minutes during off-peak hours.

<https://www.sciencedirect.com/science/article/pii/S1877050917310943>

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* Table 5: German study shows that 31 per cent of travelers would use ride-shared automated vehicles (RSAVs), 36 private cars, 27 public transportation, and 6 shared cars (excluding currently-popular walking and bicycle transportation).

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* Study of Austin TX: 320,000 employees; SAV fleet sizes of 1000, 2000, 4000; SAVs point-to-point, 1-block, and 2-block pick-up / drop-off locations (PUDOs); and reallocation of curbside parking places to PUDOs.

* Larger fleet sizes led to significantly increased ridership and trips; PUDOs led to small decreases in ridership.

<https://pdfs.semanticscholar.org/a657/1a05512429698625aad12a38b7922ecd1d3a.pdf>

CalShuttle: On-Demand, Point-to-Point, Fast, Safe Shared Autonomous Vehicles

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> Artificial intelligence "reinforcement learning" simulations show that replacing just a few human-driven cars with self-driving cars can increase traffic flow, in some cases doubling the average car speed.

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> "Lyft, Ford Motor Company and Argo AI have announced the launch of an [autonomous ride-share service](#) in Miami, U.S."

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> Alternatives include an "autonomous autobahn" and private high-speed rail projects such as those by Virgin Trains USA in Florida and connecting Las Vegas with Southern California.

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> Tesla will be the first and that many others will get there afterward and that by 2024, level 5 autonomy will be reached by Tesla.

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> Page 113: Mean Travel Time to Work 2015-2019: Silicon Valley 28.4 minutes, San Francisco 33.2.

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* BART Santa Clara County extension could have only 32,900 boardings per day.

* Ridership could be even lower, because the estimate was made using pre-pandemic 2019 figures.

* Ridership could be higher due to the Google office and residential development and SJSU riders.

<https://www.masstransitmag.com/rail/infrastructure/news/53029187/ca-how-many-people-will-ride-bart-through-san-jose-the-answer-could-define-south-bay-transit-but-nobody-knows>

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> Vehicle cost: "Autonomous sensors and computer systems ... should drop to \$1,000 – \$2,000 by the time autonomous cars are commercialized."

> Cost per mile: "... cost per mile of Google or a competitor's autonomous taxi to drop by more than half to roughly 35 cents per mile in 2020"

> Fewer personal cars: "Some Uber customers already have foregone personal cars and driver's licenses. Even today, vehicle owners—who effectively have prepaid for travel—leave their cars in the garage and use Uber, suggesting that the current system of mobility is inefficient and broken. Consequently, ARK believes that autonomous taxis are likely to become a dominant platform for point-to-point mobility in the U.S. and ultimately around the world."

> Reduce: "ARK estimates that autonomous vehicles ultimately will reduce accident rates by over 80%, contributing to a transformational public health gain. ... ARK has quantified the expected magnitude of this safety-advance by analyzing the introduction of another automation technology that has saved tens of thousands of lives: the airplane's autopilot. If autonomous vehicles contribute to a similar improvement in safety, the introduction of the autonomous car could be one of the great public health advances in history."

> Reduce parking spaces: "Spending eight- to twelve-fold more time on the road than traditional cars, autonomous taxis will likely require only one parking space in reserve per taxi, compared to the five in place today per personal car. ... By 2030, ARK expects autonomous taxis to free up roughly 250 million U.S. parking spaces worth \$4.2 trillion at today's values. More than 80% of the benefits will accrue to commercial real estate owners and municipalities. Repurposed land and buildings would deliver significant incremental returns on invested capital. In a vibrant sharing economy, homeowners could turn garages into rooms or larger yards, while commercial real estate owners might build out more offices, retail storefronts, or apartments. Municipalities will potentially lose parking fees but could sell off their parking lots to compensate, ultimately turning parking fees into real estate taxes. By our estimates, converting parking spaces would add more than \$350 billion to homeowner, commercial, and municipal real estate returns in the year 2030 alone."

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> Lithium-ion prices will decrease to as low as \$100 per kWh by 2023.

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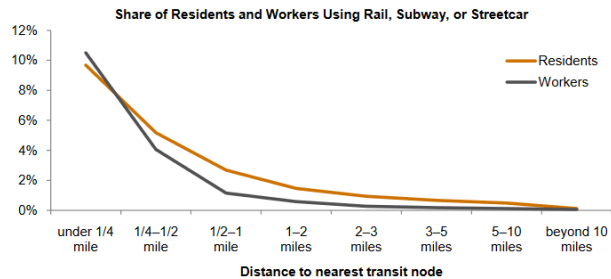
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> FIGURE 1: Transit ridership decreases as distance from transit stations increases

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"Capital equipment cost estimates for 111 new fueling stations selected for award in California varied between approximately \$1,200 and \$3,000 per kilogram hydrogen dispensed per day (kg/day) ...".

<https://www.hydrogen.energy.gov/pdfs/21002-hydrogen-fueling-station-cost.pdf>

[Kosuru2023d] Venkata Satya Rahul Kosuru and Ashwin Kavasseri Venkitaraman, Advancements and challenges in achieving fully autonomous self-driving vehicles. World Journal of Advanced Research and Reviews, Apr 6 2023.

> Discussions challenges, including infrastructure added to roadways to enable Level 5 AVs.

<https://wjarr.com/sites/default/files/WJARR-2023-0568.pdf>

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> The truck driver shortage will drive the deployment of autonomous trucks.

> Walmart and Kroger have driverless vehicles operating for last-mile grocery delivery.

https://www.bakersfield.com/opinion/community-voices/community-voices-unleash-the-potential-of-autonomous-trucking-to-support-farming/article_981ba382-73e2-11ec-a1b6-8fd606f18d3d.html

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> "Ride-hailing apps and ridesharing allow for a more flexible service than conventional bus lines, because they can react to the actual demand instead of operating on fixed routes and fixed schedules. So they can potentially offer a more attractive service for the customer by departing closer to where and when the passenger wants. Thus, they can eliminate operating costs for scheduled services which eventually run empty, because no passenger chose to take these services. Furthermore, they allow for door-to-door service which is more attractive and removes the walk time to access the next bus stop."

> "In order to realize the full potential of ridesharing-like services as part of a public transit system, ridesharing-like services will likely need to use many small vehicles instead of a few large conventional buses, because the more vehicles there are, the more frequent the service they offer can be. A large barrier to the use of more vehicles seem to be driver-related costs which according to Frank et al. (2008) amount to about 40 % of the sum of all operating and investment costs for a conventional bus in Germany. The introduction of shared autonomous vehicles (SAVs) in the future will likely remove all driver-related costs and thus could allow to replace each large conventional bus with many smaller vehicles which could offer a more frequent service without the tremendous increase in driver-related costs this would cause today. Furthermore, prices for ride-hailing services are likely to fall making them an even more attractive competitor for passengers."

> "However, using many small vehicles instead of a few large buses could increase road congestion."

<https://www.sciencedirect.com/science/article/pii/S2352146519304934>

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* 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.

https://www.cae.utexas.edu/prof/kockelman/public_html/TPTEvacSharedAVandbusstations.pdf

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> Levin: "Today, no personal vehicles can drive themselves, though some companies have started offering autonomous-taxi rides in certain cities. Those services, like GM's Cruise and Alphabet's Waymo, use detailed maps and programming to operate only in certain sections of cities. In contrast, Wayve (much like Tesla) wants to develop an artificial-intelligence-enabled vehicle that can learn to drive anywhere, even places it's never been before."

> Levin: "Gates believes personal vehicles will get self-driving capabilities only after the tech comes to long-haul trucking, deliveries, taxis, and rental cars."

<https://www.businessinsider.com/bill-gates-ai-self-driving-cars-as-revolutionary-as-pc-2023-3/>

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> "Shared autonomous vehicles (self-driving taxis) and rides (micro-transit services) are being tested in some jurisdictions but it will probably be the 2030s before they are widely available."

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[Litman2021b] Todd Litman, The New Mobilities: Smart Planning for Emerging Transportation Technologies, Victoria Transport Policy Institute, 24 June 2021.

> AV adoption and operation will benefit from dedicated highway lanes.

> Privately-owned AVs will increase purchase prices by several thousand dollars, and annual costs by \$1,000 to \$3,000, partly offset by fuel and insurance savings.

https://vtpi.org/Smart%20Growth%20Network_New%20Mobilities_24June2021.pdf

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> Photo of an ARTS vehicle in La Rochelle, France.

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> "... studies show that one automated shared vehicle can replace around 3–10 traditional privately owned cars. For the total vehicle fleet, depending on the level of automation shared vehicles could potentially replace up to 50% to even 90% of conventional vehicles, especially in combination with a high-quality public transport system. Estimates furthermore show that a decrease in privately owned vehicles can reduce the required space for parking for 90% or more, and lead to less vehicle-kilometers-traveled. 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. Automation can also help to overcome the hurdles of relocation and distribution management of the shared vehicles and avoid the hassle of finding and accessing the shared vehicle.

<https://www.sciencedirect.com/science/article/pii/S2590198220300403?via%3Dihub>

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> Survey of 6,281 households.

> 62 percent of households owned no car before carsharing; 31 percent owned 1 car.

> A survey of carsharing households: 0.47 cars per household before carsharing, 0.23 cars per household after carsharing, a 48% reduction in cars per household.

> 80 percent of the sample owned no car after carsharing; a smaller percentage reduced from 2 to 1 cars.

> Estimates that 4 to 6 cars were shed for every carsharing vehicle available.

https://www.accessmagazine.org/wp-content/uploads/sites/7/2016/01/access38_carsharing_ownership.pdf

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> "Future mobility based on CAVs aims at reducing undesirable traffic externalities, i.e. congestion, accidents and environmental damage. The analysis performed in this paper confirms that platooning has great potential in this regard. First, the frequent formation of medium-length platoons could lead to an increased road capacity due to small intervehicular space gaps. In addition, string-stable platoons could promote the ability of cooperating vehicles to reduce traffic instabilities and, therefore, enhance traffic flow stability and throughput. Second, coordination within vehicles and a lesser driver responsibility would reduce the accident rate. Third, especially truck platooning would lead to reduced energy and fuel consumptions, thus decreasing harmful emissions.

<https://pdf.sciencedirectassets.com/308315/1-s2.0-S2352146521X00087/1-s2.0-S2352146521008231/main.pdf>

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> "By the end of 2021, I believe fully self-driving cars will be in at least 15 major US cities." The article emphasizes robotaxis.

> "Amazon-owned Zoox unveiled its autonomous robotaxi on December 14. It's a fully driverless vehicle built for ride hailing. Passengers face each other. It can't be driven by a human—because there's no steering wheel. It can go up to 75 mph and can run up to 16 hours on a single charge." (With photo.)

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> While a phased evolution of robo-taxi technology and autonomous commercial driving will bring near-term disruption, widespread adoption is not expected until 2030.

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> Uber deadheading adds 69 percent to occupied passenger miles.

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<https://ieeexplore.ieee.org/document/9869489/figures#figures>

[Mouratidis2021a] Kostas Mouratidis and Victoria Cobeña Serrano, Autonomous buses: Intentions to use, passenger experiences, and suggestions for improvement, Science Direct, 2021.

> Study located in Oslo, Norway. After experiencing an autonomous bus ride:

> Section 4.2.1: 76 percent of participants indicated that they will use an autonomous bus in the future.

> Section 4.2.3: 88 percent of participants indicated they felt safe during the ride.

<https://www.sciencedirect.com/science/article/pii/S1369847820305921>

[MTC2018f] Autonomous Vehicles Perspective Paper, Horizon study (MTC, ABAG, ARUP), Jun 2018. A comprehensive approach to expectations and planning for an AV-enabled future.

> Summary of survey of experts in 2017 (page v):

Timing: 3 to 13 years until L5 AVs available for use (Author: i.e, 2020 to 2030)

Safety: +40% to +90% increase in safety

Capacity: 0% to +45% increase in roadway capacity

Demand: +5% to +40% increase in VMT

Energy/Emissions: -50% to + 100% change in GHGs

> Some desired outcomes / expectations:

Parking repurposed to affordable housing. Parking demand could reduce by as much as 90%. (Sec. 2.2.1.)

"Shared AV services could introduce a transit renaissance with improved on-demand services."

"Private mobility service operators should be required to monitor and improve their services to achieve equitable outcomes. Desired outcome: Universal access to AV services."

"Save lives and improve air quality."

> Timeframe: Likely 20% to 60% uptake of Avs by 2035. (Figure 1.6)

https://mtc.ca.gov/sites/default/files/2018-06-25_Autonomous_Vehicles_Perspective_Paper.pdf

[MTC2021j] Plan Bay Area 2050 - 4 Transportation, page 60, Metropolitan Transit Commission, Oct 2021.

> "AVs could fundamentally change the way transportation networks are designed and operated. AV adoption could shape the future of public transit, climate emissions, labor markets and access to opportunity."

https://www.planbayarea.org/sites/default/files/documents/Plan_Bay_Area_2050_Transportation_October_2021.pdf

[MTC2023b] Innovative Deployments to Enhance Arterials Shared Automated Vehicles (IDEA SAV); Metropolitan Transit Commission; Feb 8, 2023.

* MTC is sponsoring a "technical assistance grant program to fund SAV technology pilot/deployment projects."

<https://mtc.ca.gov/operations/programs-projects/intelligent-transportation-systems/connected-automated-vehicles/idea-sav>

[Mueller2021a] Joann Mueller, In Las Vegas, "driverless" cars arrive via remote control, Axios, 9 July 2021.

> "Electric AVs promise to make urban transportation safer, more affordable and more accessible, potentially easing congestion and cutting carbon emissions."

> Current activities:

1) Phoenix - Waymo driverless minivans in certain neighborhoods.

2) By 2022, Cruise, Argo AI, and others could have limited robotaxis in San Francisco and Miami.

3) Las Vegas: Halo remote-control-driven Kia Niro SUVs at pickup locations, a rider drives to their destination, and drops off the car.

<https://www.axios.com/driverless-remote-control-taxis-las-vegas-halo-0a9ded48-b682-4bee-9d09-13262cc84734.html>

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> Most of the grown to \$827 million worldwide by 2027 "will be for "static" wireless charging systems in places like parking garages, taxi stands, and bus or truck depots."

<https://www.axios.com/a-roadway-will-charge-your-ev-while-youre-driving-f2f2ad5b-3735-4948-bc50-b486f076a255.html>

[MWCOCG2016a] How proximity to transportation options affects how you get around—and where you choose to live or work, Metropolitan Council of Governments, 11 October 2016.

> "... there is a discernable point at which transit use seems to drop off most. For rail stations, that happens when distance from a station exceeds one mile. For bus, the biggest drop comes at around the half-mile point."

> "Among those with access to {HOV or Express lanes}, carpooling and vanpooling rates are about twice as high as among those without access—9 percent compared to 5 percent. And nearly half of survey respondents who use HOV and Express lanes for commuting said the availability of the lanes influenced their decision to carpool or vanpool."

<https://www.mwcog.org/newsroom/2016/10/11/how-proximity-to-transportation-options-affects-how-you-get-around-and-where-you-choose-to-live-or-work/>

[Nastjuk2020a] Ilja Nastsjuk et al, What drives the acceptance of autonomous driving? An investigation of acceptance factors from an end-user's perspective, 2020.

> Key factors in acceptance include:

- Trust, based on "... system transparency, which refers to the degree of comprehensibility and predictability of the operations of autonomous vehicles ...".

- "... personal innovativeness positively affects perceived ease of use and perceived usefulness."

- "... innovators are also more likely to accept autonomous driving, especially when they have already experienced newer technologies in the automotive context."

- "... the relative advantages as positively associated with both perceived usefulness and attitude toward using autonomous driving."

- "... perceived enjoyment increases the intrinsic motivation to use autonomous driving, and thus makes interaction with autonomous vehicles easier."

- "... cost reductions will improve the perceived cost-benefit ratio, thus positively influencing the intention to use autonomous driving."

<https://www.sciencedirect.com/science/article/pii/S0040162520311458>

[Newman2021a] Rick Newman, When self-driving cars are coming, for real, yahoo!news, 21 July 2021.

> By 2025 for Level 4 autonomy.

<https://news.yahoo.com/when-self-driving-cars-are-coming-for-real-164631730.html>

[Othman2021a] Kareem Othman, Public acceptance and perception of autonomous vehicles: a comprehensive review, Springer Link, 26 February 2021.

> Extensive discussion of software approaches to enhance safety and many other factors.

> A US survey by Casley et al of 467 respondents regarding AVs:

- 82 percent ranked safety of the most important factor.

- 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.

- Manhattan, New York shared AV simulation showed an 88 percent cost reduction from \$7.80 to \$0.80 per trip due to reduced ownership cost, operating expenses, and central coordination.

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> AVs can: reduce vehicle ownership; provide excellent service; enable passengers to engage in productive activities; reduce parking demand by 80 per cent to 90 percent; increase coverage and accessibility for aged and disabled persons, and rural residents; be used as delivery vehicles, during pandemics and generally; reduce traffic accidents, injuries, deaths, and health care costs.

> "... 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."

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> "AVs improved traffic flows by decreasing travel time and delay and increasing vehicle speed. As the penetration rate increased, the improvement also increased."

> "This study indicated that even a low penetration rate of AVs can improve traffic flow on urban roads. ... With car-sharing trends and shared automated vehicles (SAVs), planners need to rethink issues around car use and road capacity. Probably, there will be an overcapacity of current road networks for car use demand in the future. In that case, city planners need to redesign roads for cities or to find another use for the spare capacity achieved by using AVs."

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* Some people will choose to use AVs in zero-occupancy mode to run errands; those people will be more prone to own AVs rather than use shared AVs. This would lead to more AVs on the road, increasing traffic congestion; policies should be put in place to discourage such use.

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> *[This author's note: The results below might have implications for California High-Speed Rail as well.]*

> "With an initial scenario assuming an operating cost of AVs that is 118% of traditional cars, two outcomes are observed that are solely based on model results. First, the availability of AVs severely digs into the airline travel market, reducing airline revenues to 53%. Second, the introduction of AVs results in a shift of destination choice, increasing travel in further distances for personal vehicles by 9.6%, but favoring closer distances across all modes with a 6.7% overall trip-miles reduction."

> One study "explored mode choices in Michigan for trips over 50 miles in length, and forecasted that over 25 percent of airline trips under 500 miles will shift to AVs. Such changes will have important impacts on airlines, infrastructure planning and future land use (especially around long-distance transportation facilities), highway congestion, and the travel industry more generally."

> One study noted that "19% of Americans with disabilities report leaving their homes relatively infrequently, and are less likely to take long-distance trips ..." Another 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."

> "AVs reduce the burden of travel for drivers and may improve the quality of travel for passengers, who can now focus on more meaningful interactions with those previously focused on driving. The value of travel time (VOTT) of the driver (or his/her willingness to pay to save travel time) is expected to fall, by 20 to 50 percent or more, so the generalized cost of travel can fall by several dollars per hour to \$6 or more per hour, for many travelers."

> Table 1: After AV market penetration of 51%, airline trips less car+AV trips increase by 105 to 112 percent, and airline trips reduce decrease by 53 percent.

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CalShuttle: On-Demand, Point-to-Point, Fast, Safe Shared Autonomous Vehicles

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> Section VI: Functional Performance Indicator Trends, 2017:

- Operating costs per passenger mile: \$2.29.
- Farebox recovery ratio: 12.8 per cent.
- 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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> Connected AVs, and SAVs (shared autonomous vehicles) will result in: 28 percent fewer vehicles, 44 percent fewer parking spaces, 30 percent less travel time, 66 percent less emissions, and 87 percent fewer accidents.

> " With smartphone applications for autonomous car-sharing, millions of people could avoid being packed like sardines in trains and buses every morning, only to get stuck in hour-long traffic jams."

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10 minute refueling time at a centralized depot

Proven durability: fuel cell lifetime of 30,000+ hours

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> Success factors from this study: 1) monetary savings; 2) convenience; 3) time saving (shorter wait times and shorter travel times); 4) flexibility; 5) comfort.

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> The OECD/ITF 2016 study "also predicts total vehicle kilometres travelled would be 37% lower than the present day, although each vehicle would travel ten times the total distance of current vehicles."

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> Page 63: "This study modeled the impact of replacing all cars and bus trips in Lisbon, Portugal, a midsized European city, with mobility provided by fleets of shared automated taxis and shuttle busses. Among the key findings were that 97 percent fewer vehicles (cars, shuttle busses, and full-size busses) would be needed to serve all trips, 95 percent less space would be required for public parking, and 37 percent fewer kilometers would be traveled by the vehicles. The study also estimated that each vehicle would travel ten times the total distance traveled by current vehicles. The benefits of intensive use of vehicles are large: much lower cost per passenger (since depreciation and operating costs are spread out over many more occupants) ..."

> Page 63: "A study of New York City by researchers at the Massachusetts Institute of Technology came to similar conclusions: three thousand four-passenger cars could serve 98 percent of taxi demand in New York City, with an average wait time of 2.7 minutes. The researchers also found that 95 percent of taxi demand would be met by just two thousand ten-person vehicles, compared with the nearly fourteen thousand taxis that currently operate in New York City. They used an algorithm that reroutes cars in real time to serve incoming requests."

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Vehicles removed from the road per carsharing vehicle (vehicles): 5 to 20.

Members selling personal vehicles (percent): 15 to 33 (outliers 0.14, 2.5)

Members avoiding vehicle purchase (percent): 25 to 71 (outliers 0.19, 0.44, 2 to 5)

> Impacts of microtransit from RideKC: Reasons to use (percent):

Cheaper: 56 percent, comfort: 39 percent, flexibility: 33 percent.

Acceptable fare: \$2: 100 percent, \$3: 23 percent).

Service area: 67 percent of respondents would use / use more with a larger service area.

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CalShuttle: On-Demand, Point-to-Point, Fast, Safe Shared Autonomous Vehicles

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- An intuitive, easy-to-use smartphone app for all passengers (or their caretakers) that includes built-in accessibility features like voiceover technology, adaptive font size, and enhanced contrast.

- A web portal for those who have internet access through a desktop computer.

- Telephone, SMS, or email booking.

- Optional ride booking kiosks at major transit hubs.

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- First-and-last mile. In most places, high-frequency transit isn't within walking distance of where most people live and work. Microtransit connects people to the buses and trains that will then connect them to everything else, while taking single-occupancy cars off the road.

- Transit deserts. It's not easy to build a transportation network in places that lack the population density necessary for efficient fixed-route buses or trains. Microtransit creates a more convenient and accessible service for riders in these areas.

- Equity and accessibility. Public transit is often a critical lifeline for seniors and people with disabilities.

Microtransit optimizes typically inefficient paratransit options, creating real-time bookings, higher quality service, and reducing trip costs with more efficient and equitable shared rides.

- COVID-19 safety. As both 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.

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> Figure 5: Six selected substation costs range from \$6.3 million to \$15.8 million, with an average of \$10.7 million.

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> Would you ride in an autonomous vehicle if given the opportunity today?: Yes: 62 percent.

> Which aspect of autonomous driving do you find most compelling when it comes to safety?: Non-driver doesn't drink - 56 percent; not distracted - 55; follows road rules - 54; perceive and respond to surroundings - 52; all of the above 31.

> If you didn't have to be the driver, what would you do with your extra time?: Enjoy the city, relax, call/text, work, read/watch a video, check social media.

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> Waymo to start operating autonomous vehicles in Los Angeles in the coming months.

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[Wenzel2019a] Tom Wenzel et al, Travel and Energy Implications of Ridesourcing Service in Austin, Texas, Lawrence Berkeley National Laboratory, 2019.

> RideAustin deadheading adds 35 percent to occupied passenger miles.

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* Request for Information announcement for an upcoming "Shared Autonomous Vehicle (SAV) systems engineering project to explore the feasibility of deploying a first/last mile transit service in the vicinity of the East Dublin/Pleasanton Bay Area Rapid Transit (BART) station. This service would serve as a first/last-mile connector between the BART station and nearby business, residential, and commercial developments."

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> "Autonomous vehicles will change the land uses in the metropolitan areas. ... Many large parking lots can be shifted into alternative uses. ... the author claims that almost a third of the central area in major cities in the US is dedicated to parking."

> "... autonomous vehicle can drop passengers off at almost any location at any city and then instead of cruising for parking, the autonomous vehicle can park itself in a remote location in a rural fringe of the city where inexpensive land is more readily available. ... An autonomous vehicle can park in a tighter parking slot without having a collision with the nearby vehicle. ... the author calculates that an average parking can be reduced by 15% because of the compact parking slots."

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> "Driverless cars are much more comfortable and restful for passengers than public transportation. Moreover, union stations are not often in a close proximity of the passenger, so the passenger should 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."

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* Bishop Ranch business park driverless autonomous shuttles debut, with 4 stops on a limited route.

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> Sliding doors.

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> "Carpooling is poised to address the current issues in transportation such as car ownership, traffic management, transport economy, time management, to name a few. Furthermore, carpooling has been proved beneficial in traffic congestion control, the effect on the environment, economy, rush hour problems, and many more. However, these advantages have brought many challenges that the research community has tried to address, and the current carpooling service providers have adopted few. ... [These include] scheduling, pricing, and communication ... [and] security and privacy in carpooling."

<https://dl.acm.org/doi/pdf/10.1145/3501295>

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.