Transportation Options Through a PRT Lens

A Project of LoopWorks
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Facts and figures in this paper were collected over nearly 2 decades. Readers are encouraged to inform the author of appropriate corrections along with a URL reference that validates them. Send suggested updates to Rob.Means@electric-bikes.com

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Executive Summary

The aim of this paper is to start a conversation about – and focus decision-makers' attention upon – transportation challenges our communities face, and provide an educational briefing on a number of possible solutions.

This paper attempts to concisely inform readers about the complexities of transportation, provide some basic rules of thumb, establish guidelines for choosing between solutions/options, and culminates in recommendations for mobility in the South Bay Area of the San Francisco Bay bioregion.

To provide grounding in the complexities of transportation, various options in the South Bay are viewed through these six lenses (supplemented with handy rules of thumb):

1. moving people vs. moving stuff (below)
2. corridor vs. network (page 3)
3. throughput capacity (page 4)
4. multi-modal trips and connections (page 6)
5. costs to build and operate (page 8)
6. speed vs. door-to-door time (and BRT-Light's potential) (page 13)

With that grounding, and an assumed familiarity by the reader with existing transportation options, two newer options and their potential are examined in depth:

1. fleets of driverless vehicles: disruptive technology => Transport as a Service (TaaS) (page 15)
2. potential of PRT/ATN (Personal Rapid Transit / Automated Transit Network) (page 22)

Having reviewed various factors in our transportation equation, we come to the critical question: What combination of options makes sense for this defined area? ***Appropriate Application of Technologies*** (page Error: Reference source not found) outlines a value equation that could help decision-makers choose preferred options and how to integrate them.

LoopWork's Vision (page Error: Reference source not found) starts with their Mission to provide high quality, carefree, in-town, elevated travel at no cost for Milpitas residents and visitors that is clean, safe, climate friendly, efficient and will provide stable employment. The vision, however, extends worldwide: Vision: The LoopWorks dual-loop PRT project inspires rapid and widely-implemented advanced transit that dramatically reduces CO_2 emissions from the transportation sector of societies.

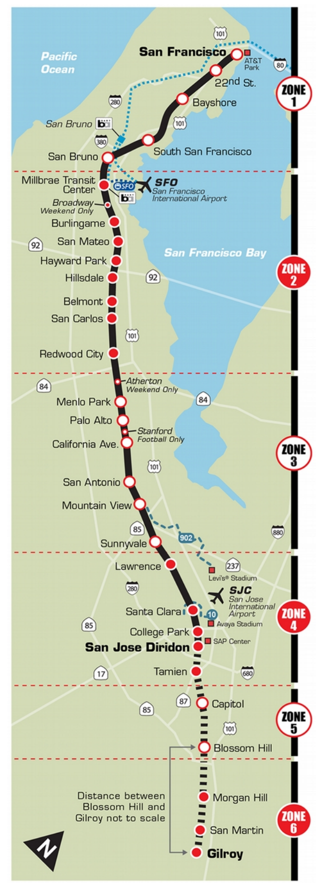
Examples of available options that support those values - and proposals that may not - are explored. ***Issue Areas NOT Addressed*** (page 32) are mentioned before the concluding section (page 34).

The aim of this paper is to start a conversation and focus decision-makers' attention on the scale, speed and impact of the impending disruption in the transportation sector. Policymakers will face choices in the near term that will have lasting impact. At critical junctures, their decisions will either help accelerate or slow down the transition to newer technologies.

Moving People vs. Moving Stuff

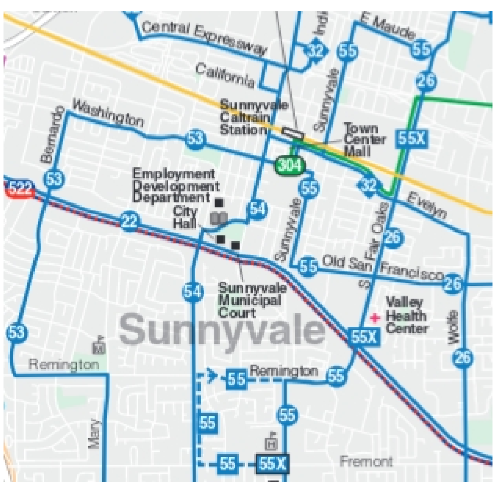
This White Paper will focus on the movement of people rather than the "stuff" of a society (food, building materials, consumer goods, garbage, recyclables, etc.). *Rule 1: As with roads and motor vehicles, designing a system that works well for people goes a long way toward a system that works well to transport stuff.* When a transportation system congests for people, it also congests for cargo shipping as we can daily see on congested roadways.

Corridor vs. Network



Fixed rail systems like BART and Caltrain (right) are fundamentally corridor transportation systems that serve a "string of pearls" (stations) along the corridor. Old time rail systems that served towns and cities along the line served them well for long-distance travel, as do modern equivalents that serve to transport people between cities. *Rule 2: Corridor systems with on-line stations have fewer stations spaced farther apart which allows for higher speeds between stations.*

Rule 3: Network systems like roadways generally run at lower speeds and serve to connect many origins with many destinations in a defined area. For example, sidewalks and bike lanes/paths interconnect to create pedestrian and cyclist networks.



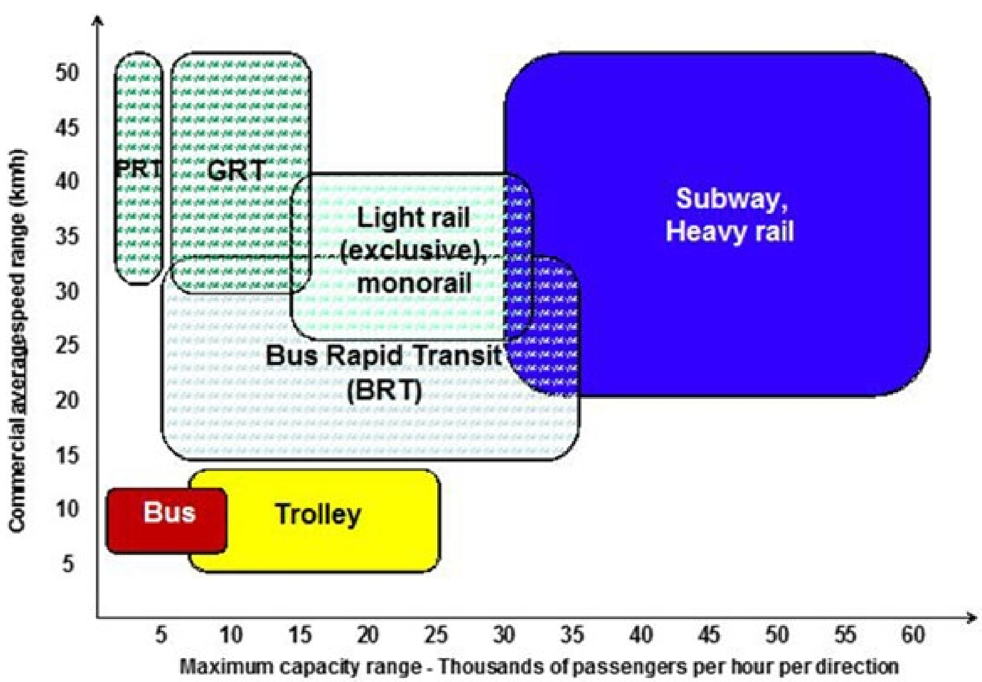
Because South Bay cities have been designed around the car and a network of roads, they sprawl rather than concentrate around corridors. A single bus route is usually a corridor with buses running from one end point to the other, then back again along the same route. Bus networks (left) are composed of many bus routes, some of which intersect and allow for transfers from one bus to another. That intersect-and-connection-transfer to another vehicle is how transportation systems interconnect the various corridor and network sub-systems.

Rule 4: Networked systems come in two flavors, those that require a transfer to another vehicle and those that don't. While bus and fixed-rail (LRT, BART) networks require transfers, car and cyclist networks do not.

Multiple PRT Loops => Network Without Transfers
Another network technology that does not require a transfer to get to any part of the network is an Automated Transit Network (ATN) composed of Personal Rapid Transit (PRT) cabs traveling along elevated guideways (right). Generally designed as one-way loops, a simple PRT system can grow into an ATN by connecting multiple PRT loops (as shown below in **Networks**).

Throughput Capacity

Throughput capacity depends upon loading factor per vehicle and headway (time between vehicles). Capacity of a transportation corridor can be increased with larger vehicles, shorter headways, or both. As you can see in the following diagram, PRT (Personal Rapid Transit), GRT (Group Rapid Transit), Light Rail, and Heavy Rail all travel at roughly the same speed (20 – 40 mph), but potentially transport widely differing numbers ranging from a few thousand to more than 50,000 passengers/hour.



The figure above shows that PRT and GRT systems fill a "white spot" on a transit planner's map: medium capacity and high average speed (for any origin-destination pair). Characteristics of other systems may differ from those shown in the figure; the intention is to show the relative placement of PRT and GRT systems rather than to show precisely the characteristics of all systems in absolute values.

Corridors

As an example of high-volume transit, BART cars can seat 60, but can carry over 200 customers in a crush load. Trains of 10 cars each running at 2-minute headways (30/hour) can move a maximum of

60,000 passengers per hour. While these numbers validate the "Subway, Heavy Rail" estimate of capacity, other estimates suggest that the diagram above may be over-estimating capacity (thousands of passengers per hour) for BRT and LRT. For example, although LRT systems may be designed for high volume, current actual limit of any operating route in the U.S. is 1200 passengers per hour.

Rule 5: Maximum capacity on a corridor is rarely achieved, while the average loading is less than half of theoretical maximum capacity. For example, BART to Berryessa at 10 miles and an expected 24,000 daily riders (both ways) works out to only 1200 people per one-way mile per day – far from the theoretical maximum. Likewise, Caltrain's weekday average ridership is about 25,000 of which about 2,000 (or 8.6%) bring their bikes aboard as their last-mile solution.

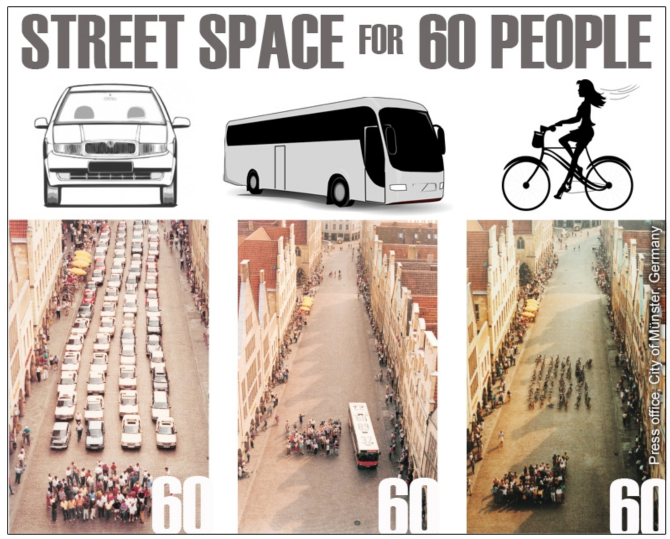
Not pictured in the diagram above are roadways. The maximum volume (or saturation flow rate) of a lane of automobile traffic is about 2000 vehicles per hour per lane. Thus, a 2-lane roadway (1 lane going each direction) with an average occupancy of 1.5 passengers per vehicle (rather than peak-hour average around 1.1 person occupancy) could be pictured at the left side of the PRT zone in terms of passengers per hour per direction. There is considerable evidence from California freeways that 2,000 vehicles/lane/hour can be sustained providing that no incidents or backups occur. This assumes demand and capacity in balance of course. The Transportation Center at UC Berkeley has determined max throughput is at uniform speeds of 50 to 55 mph. Maintaining that consistent speed is the trick. As most of us have experienced, autos cruising down the freeway sometimes suddenly find themselves in a jam. What caused the mess? This 40-second video shows how it happens, while this 2-minute Scientific American video explains how it happens.

Los Angeles' extensive HOV lanes show the peak-hour average vehicle occupancy goes up to about 1.25, thus validating that carpools do increase vehicle occupancy. However, the overall throughput of people on freeways with HOV lanes (and especially HOT lanes), is marginally better and often less than freeways without designated HOV or HOT lanes, especially during the AM peak-driving period.

Networks

While the capacity of corridor transit systems can be easily represented in the diagram above, grasping the capacity or throughput of a network system is more difficult. Those of us who drive in the South Bay Area, however, have an experiential "feel" for network capacity. We know that all those vehicles from lightly-traveled but networked neighborhood streets somehow congest those huge freeway corridors. Likewise, a networked transit system has the potential to accommodate more passengers than a high-volume corridor. *Rule 6: Adding parallel lines to a low-volume transit network adds capacity that can eventually exceed high-volume corridor transit throughput.* This is how a roadway network of low-capacity streets can add up to supply more vehicles per hour than larger-capacity corridor systems can absorb.

Another issue that arises when talking about capacity is handling surges of passengers that unload when a full train stops at a station or when sports fans leave at the end of a game at Levi's® Stadium. High-capacity transit like BART handles surges along a 700-foot long platform. Low-capacity vehicles use small loading/unloading spots called berths. *Rule 7: Low-capacity transit like PRT can use multiple stations each with multiple berths – all operating in parallel – to achieve high capacity.* Using an estimate of 15 seconds as the average time between PRT departures, 10 berths would be required to clear 120 people in 3 minutes (4 people/min/berth X 3 min X 10 berths = 120 people). It's likely that 2 stations (with 5-7 berths each) would adequately serve BART and Caltrain stations. If more than 120 people want to exit the station via PRT (instead of the other options) - or 3 minutes is deemed too long - additional stations could be added.



Here are **two more ways to visualize capacity**. Example 1: It takes 3 lanes of a given size to move 40,000 people across a bridge in one hour using automated trains, 4 lanes to move them on buses, 12 lanes to move them in their cars (assuming 3.5 passengers/car), and only 2 lanes for them to pedal across on bicycles. In the case of bicycles, multiple vehicles (bikes) can run in parallel within the width of a lane.

Example 2: What is the congestion point for a PRT system? At 3-second headways and 4 passengers per vehicle, maximum capacity is 4800 passengers/hour. Reducing that headway to 2 seconds (spacing recommended between cars on a freeway) yields 7200 pax/hr, which is more than enough for most routes, especially in a network with parallel lines spaced 1-2 miles away on both sides. Thus, a single PRT guideway can transport as many passengers as heavy rail using 6-car trains, each car carrying the maximum of 200 passengers each and 10-minute headways (6 x 200 x 6 = 7200 pax/hr).

Multi-Modal Trips and Connections

Rule 8: Trips are multi-modal. Even driving your car from your garage directly to your destination's parking lot and walking to the entrance involves 2 modes: the primary link (car) and the "last mile solution" (walk). Solutions to that "last mile" (which may be much longer than a mile) are abundant: walk, skateboard, kick scooter, electric folding scooter, folding or rigid bicycle (electric-assist or not), Zipcars, taxi cabs, corporate shuttles, Uber/Lyft, and (soon) driverless vehicles. Switching between modes – or even between vehicles within a system – involves moving from one vehicle to another. Each of these transfers may involve a waiting period.

Rule 9: Switching modes or vehicles can be quick and easy unless the transfer requires a wait – largely because waiting time seems longer to people than it really is. Unfortunately, public mass transit systems often involve one or more transfers that require waiting time. That transfer wait-time adds significantly to the total door-to-door time. For example, riding BART to Antioch involves a simple cross-platform transfer plus an 8-minute wait between Pittsburg/Bay Point and Pittsburg Center stations; due to scheduling, west-bound riders do not incur that 8-minute wait.

Three solutions to the wait-time problem are 1) frequent service (e.g. a bus route with 6-minute headways), 2) on-demand service that is summoned to meet you at the transfer location (relative/friend or Uber/Lyft), and 3) service by ready-to-go vehicles available at the transfer location (e.g. taxis or rental bikes waiting at a train station, or the portable mode brought by the user on the train or bus).

Why bikes and scooters, and why now?

1

ADDRESSING THE FIRST/LAST MILE

Cities are getting more congested due to urban migration, but fewer people are using public transport, creating more traffic on the roads.

Bikes and scooters can connect multiple points of transit to facilitate the use of public transport and replace cars for shorter-distance trips.

2

THE RISE OF DOCKLESS SYSTEMS

A confluence of maturing technologies – namely mobile payments, IoT, and GPS – **has allowed companies to launch dockless sharing platforms**.

Dockless systems are more convenient for the user and also require lower capital costs for platform operators, making it easier to scale and maintain profitability.

3

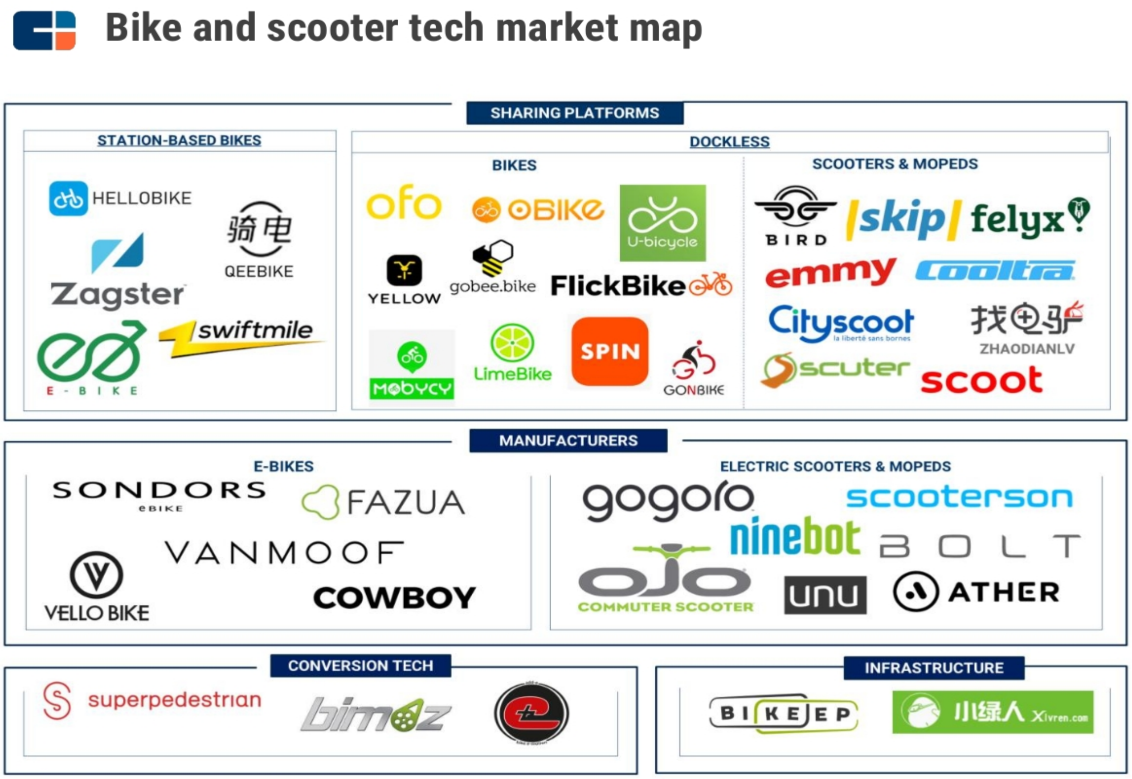
ELECTRIC VEHICLES CAN FINALLY SCALE

Battery costs for electric vehicles are falling and are expected to continue to drop moving forward.

Lower manufacturing costs will make electric bikes and scooters more affordable, allowing sharing platforms to more cost-effectively scale their systems.

A corollary to Rule 9 is that switching modes or vehicles can be more costly to the user in time or money when individual transit systems in an area have not integrated their payment systems.

In the South Bay, first/last mile service to/from transit is generally much less of an issue than the (in)frequency of the transit options themselves.



Cost to Build and Operate

Rule 10: The more stuff required to build a transportation option, the more it will cost. Freeways cost more than bike paths. Construction of the 880/237 interchange in 2001-2005 required 11,690 cubic meters of concrete, more than 1.3 million Kgs. of steel, and 20,319 meters of piles pounded into the ground. While LRT track can weigh up to 2,000 lbs./linear foot, guideway for PRT can be as little as 140 lbs./linear foot - which helps explain the cost difference between the two technologies. Stuff costs money.


Compare size of elevated LRT (gray) with PRT-sized guideway (small-gauge blue curving guideway is Cal Expo monorail.)

Rule 11: A transportation option that costs X dollars at ground level, will cost 2X dollars when elevated, and 3X dollars when under-grounded. For example, the 10-mile BART extension from Warm Springs to Berryessa at ground level cost about $230M/mile, while the proposed BART Burrow (formally known as BART Extension Phase II) is projected to cost $800M/mile ($4900M for 6 miles).

Cost to Build (Capital Costs)
Following are ballpark estimates of what various transportation technologies cost for bi-directional (corridor) travel. While the specific costs and estimates will vary, each mode generally maintains its cost-position relative to the others.

Transportation Technology	Bi-Directional Cost
Bus Rapid Transit (BRT) - when re-purposing existing roadway	$4-9M/mile
Freeway/Expressway Lanes - at ground level (no land acquisition)	$10-20M/mile
Personal Rapid Transit (PRT) - elevated	$20-60M/mile
Automated People Mover (APM) - at ground level	$30-50M/mile
Light Rail Transit (LRT) - at ground level	$60M/mile
Bay Area Rapid Transit (BART) - at ground level	$130-230M/mile
Pedestrian Over Crossing (POC) - elevated	$150M/mile

Bus Rapid Transit (BRT) - $4-9M/mile when re-purposing existing roadway
Rule 12: Capital costs for a technology vary widely depending upon constraints. In 2016, VTA estimated cost of the 10.5-mile BRT upgrade on Alum Rock Avenue to cost $60-70M ($6M/mile). However, a 2011 San Jose Mercury-News article on BRT (New Look for El Camino) outlined two proposals: 1) 3 miles of lanes dedicated to express buses for $118M ($39M/mile), or 2) 10 miles for $240M ($24M/mile). (As outlined in the section Speed vs. Door-to-Door Time below, prioritizing signals along a roadway could be a far cheaper BRT solution than creating dedicated lanes.)

Freeway/Expressway Lanes - at least $10-20M/mile at ground level (without land acquisitions)
The 3-mile widening of I-880 freeway between Montague Expressway and U.S. 101 (from 4 lanes to 6 lanes) cost $74M ($24M/mile). Widening US-101 between Metcalf Road and Cochrane Road from 4 to 8 lanes without land acquisitions cost only $4M/mile ($64M for 7.5 miles for 4 lanes rather than 2). The Sunol grade HOV lane southbound between Hwy. 92 and Calaveras Boulevard cost $84.4M for 13 miles ($6M/mile), but the complementary northbound HOV lane will cost $127.3M ($10M/mile) for a total of $16M per bi-directional mile.

Personal Rapid Transit (PRT) - $20-60M/mile elevated
PRT technology is generally designed as loops with one-way, elevated guideways. While guideways and cabs vary between various systems, many in the industry are using $15M/mile that includes guideway, stations and a moderate complement of cabs. (See **Potential of PRT/ATN** below.)

Automated People Mover (APM) - $30-50M/mile at ground level
Measure A in 2000 authorized connecting Mineta San José International Airport with Caltrain and First Street. In 2010, VTA staff presented a plan estimated at $600M for the 4 bi-directional miles using

Automated People Mover (APM) technology. That number could have been higher except that VTA hoped to use the BART tunneling equipment to contain costs. The proposed level of service is a tram every two minutes to move at least 1200 people per hour.

APMs come in three flavors: cable drive, monorails, and rubber tires. The cable-driven Oakland connector between BART and the Airport was estimated to cost $232M and carry 20,000 daily passengers when opened in 2008. The BART Board of Directors on March 28, 2002 approved the link that would uses an elevated guideway for the 3.2-mile corridor route. In 2008, the estimated price had risen to $450M -- a 25% increase to be paid for by a public/private partnership that charges a $5 fare.

<u>Light Rail Transit (LRT)</u> - $60M/mile at ground level
The proposed 2.5-mile LRT extension from the Alum Rock Station to the Eastridge Transit Center is projected to cost $453M ($181M/mile) for design, right of way, utilities and construction of elevated light rail tracks along Capital Avenue.

<u>Bay Area Rapid Transit (BART)</u> - $130-230M/mile at ground level
Rule 13: Dirt costs a lot in our area. Thus, rail corridors are often selected based on where the public already owns the land. For example, costs were dramatically reduced for the 12-mile Dublin/Pleasanton BART extension which was completed in 1998 for $571 million ($47.5M/mile or $74M/mile inflation adjusted) – primarily routed down the freeway median without right of way issues. By contrast, the 10-mile BART extension from Warm Springs to Berryessa at ground level cost about $230M/mile partly due to right-of-way costs.

Another way to reduce costs is to use a different technology. In addition to using the median of State Route 4, the BART extension to Antioch shaved costs by using Diesel Multiple Unit (DMU) trains running on standard gauge rail. Offering capacity of an estimated 2,400 people in each direction, per hour, during commute periods, the 10-mile extension cost $525M ($52M/mile) rather than the estimated $1300M ($130M/mile) for extending BART's traditional electric-powered, non-standard-gauge rail line.

<u>Pedestrian Over Crossing (POC)</u> - $150M/mile elevated

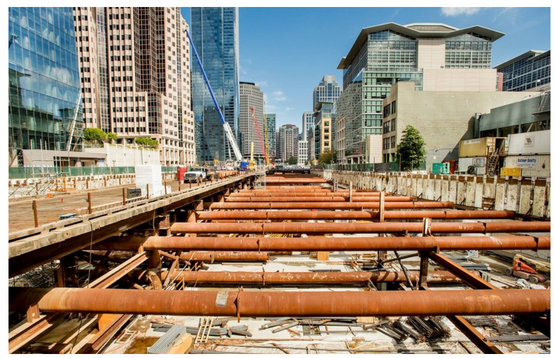
Infrastructure for pedestrians and cyclists also costs. At a new housing development in Milpitas, a pedestrian bridge over Lower Penitencia Creek near McCandless Drive was built for $650,000 (funded by the Transit Area Specific Plan impact fees). At the other end of the cost spectrum - at an estimated $14M - is the 200-foot-long POC over Montague Expressway in Milpitas that connects the BART parking garage with housing and retail ($369M/mile). The Don Burnett Bicycle-Pedestrian Bridge (shown here) is a 503-foot-long cable-stayed bridge over Interstate 280 (connecting Cupertino and Sunnyvale) that was completed in 2008 at a cost of $14.8 million ($155M/mile). The ~300-foot cable-stayed pedestrian bridge at the Warms Springs BART station, originally estimated at $25M ($440M/mile), is now estimated at $35M ($616M/mile) largely due to the red-hot construction environment in 2018 Silicon Valley.

Other Considerations

When calculating capital costs, one must consider the ongoing **debt service** of those capital costs when paid for with borrowed money. That money may cost 5% per year from a privately-owned bank or less from a publicly-owned bank.

One metric used by transit professionals to compare options is the **capital cost per rider**. Although this White Paper does not provide those figures, they may be a better metric for comparing costs than the just the actual cost per mile.

Three other metrics besides capital costs that could be included in determining the value/cost of a transit option include 1) the travel time using that option (see Speed vs. Door-to-Door Time below), 2) the degree of disruption during construction, and 3) the time to build the option. As an example of the latter, the BART line from Fremont to the Santa Clara Caltrain station was proposed in 2000. The first phase to Berryessa is expected to open in 2019, and the remaining 6-mile phase in 2028. **In a time of rapidly accelerating Climate Chaos, time may be more valuable than money.**



BART construction under Market St.

Operation & Maintenance (O&M)

The cost to build a transportation option – capital costs – is the big, up-front investment. Every year after opening, however, each system will require roughly 3-5% of capital cost for operations and maintenance (O&M). Some of that cost is paid from farebox revenue, but for publicly-owned transit in the South Bay, most O&M is paid from public funds generated through taxes.

Operating expenses for the entire BART system were estimated at $656M for fiscal year 2016. Without adding up all the various segment costs and inflation-adjusting them to come up with a total capital cost for the system, we can estimate total cost at $16,400M by using a 4% O&M factor. ($656M/.04 = $16,400M).

In 2012, farebox revenue for Caltrain was $44M while another $8M came in from other revenue streams. With $103M in expenses, only a 53% subsidy was required. BART claims 62-65% of O&M costs are recovered from fares (although considering all the deferred maintenance, this figure may be overstated).

When thinking about operating costs, many people initially think of fuel costs. However, typically transit systems spend roughly 70% of O&M budgets on labor (drivers and support staff). In 2016, 73% of VTA's costs/passenger-mile were spent on labor (salary, wages, benefits) while 10% went to materials and supplies.

Since labor is such a big part of operating a transit system, why have no fully automated metros (without train-assigned attendants) been built in the Bay Area when they are standard practice around the rest of the world?

Led by France in the 1980s, the driverless metro industry is now well developed and global. UITP (Union Internationale des Transports Publics) observes that there are sixty-two fully automated lines around the world.

Valley Transportation Authority (VTA) uses fare revenues to pay 10% of O&M for their transport network. From where does the other 90% come? Over half comes from local sales taxes, a regressive tax that impacts the poor more than others. The poor, however, use transit more than other groups, and thus it could be argued that they come out ahead – at least those who actually use public transit. Given the regressive nature of sales tax, and our society of extreme wealth inequality, perhaps other fund-raising methods should be explored. Both pollution fees and free-loader fees could raise funds while diminishing incentives to pollute and abuse the commons. Here's a link to some possibilities: http://meansfordemocracy.org/budget.html#fees

PRT O&M

The oversized PRT-like system at Morgantown began in 1975 as a transportation research project. On a typical day, 15,000 passengers travel between the five stations along an 8.7-mile track, riding in 71 self-propelled cars that travel at speeds of up to 30 mph. The project originally cost $120 million, however much of that was due to a poor design/build process that over-specified the guideway to accommodate 100-passenger vehicles (4- to 5-times heavier than vehicles actually used). In today's inflation-adjusted dollars, the cost was $539M. Now, a crew of 55 keeps the system operating six days a week by repairing the aging cars and guideway, and often scrounging for hard-to-find parts.

The university spends $5 million annually to operate the system which, as a percentage of capital costs, ranges from 4% down to 1% ($5M/$120M or $5M/$539M). On a per-mile basis, the O&M cost works out to $575K/mile ($5M/8.7mile). Remember, those costs are for a customized GRT system using old technology in a location that regularly freezes. O&M for small-cab PRT system in the Bay Area should be substantially lower.

Here are estimates of O&M **costs per passenger mile** for various technologies:

PRT = $0.15, commuter rail = $0.28, LRT street cars = $0.45, buses = $0.55.

(Buses in Silicon Valley have lower-than-LRT operating costs due to low transit demand. Buses tend to have lower costs per vehicle-mile, but rail often has lower costs per passenger-mile due to higher load factors.)

Speed vs. Door-to-Door Time

By definition, a Rapid Transit Corridor offers average speeds of 20 mph or greater (including stop times). In the United States, federal law has used the term "high-speed rail" as rail services "reasonably expected to reach sustained speeds of more than 125 miles per hour". When station stops are included, that 125 mph "sustained speed" will be substantially reduced.

BART trains can speed down the track at 80 mph, but their average speed is 40 mph due to station stops (slowing down, dwell time at station, and acceleration time). At either speed, the time spent on BART is just a part of overall door-to-door time. For example, someone going from their home in Milpitas to a demonstration in Oakland needs time to get to the BART station, an average 10 minutes waiting for the train (20-minute headways), the actual time on BART (51 minutes), and the time to get to the demonstration site. Either or both of the links between a BART station and a destination/origin can also involve a transfer and associated wait time. The ability to reduce door-to-door time is one BIG reason cars are so popular.

Here are two other examples of transit maximum-versus-average speeds:

LRT maximum speed = 55 mph, VTA light rail system average speed = 16 mph
BRT maximum speed = 55 mph, average speed = 23 mph

Overlooked BRT-light Potential?

Travel time for the 10-mile stretch of Santa Clara-Alum Rock dedicated-lane BRT service (from HP Pavilion to Palo Alto) is estimated to be only 26 minutes (vs. 29 minutes for cars), yielding an average speed of 39 mph thanks to signal prioritization. The possibility of dramatically improving the speed of mixed-flow BRT-light (without dedicated lanes) from an average 23 mph toward 39 mph warrants more study.

Average vehicular speed (and road capacity) is generally limited by signalized intersections (rather than congestion). Tweaking those signals to give special treatment (green lights) to BRT could provide some (or most) of that 23-to-39 mph speed increase <u>without</u> creating a dedicated lane between intersections. "Tweaking" is used because buses only need preempt about 15 seconds out of 5 minutes - that is, only when a bus at 5-minute headways is approaching the intersection. In the other 285 seconds (95% of the time), no capacity is taken from cars. Even that 15 seconds could frequently be reduced to several seconds when buses approaching a signal that just turned yellow extends that yellow light long enough for the bus to pass (known as "traffic signal priority"). Signal preemption actually triggers a green light as the bus approaches.

Here are the numbers: using a standard 4 seconds of yellow-light caution time, a bus approaching a red signal would need 4 seconds of yellow-light time to finish the existing cycle phase (i.e. stop the cross traffic), plus 4 seconds of green-signal time while approaching the intersections (so braking time is available if needed), plus 2 seconds of green-signal time to pass through the intersection, plus 4 seconds of yellow-light time behind the bus – a total of 14 seconds – before the next cycle of traffic signaling starts.

Bus Signal Priority in Santa Clara County, California provides background for, and analysis of, bus signal priority applications used by the Valley Transportation Authority (VTA) along Route 522, a rapid bus route. In addition to describing signal prioritization technology used by VTA, the report assesses the increase in average operating speed provided by the Intelligent Transportation System (ITS) application of bus signal priority (BSP) in rapid bus operation as compared to traditional local bus operation.

For a variety of reasons—including technology incompatibilities and competing priority of light rail transit—not all signals in the Route 522 corridor are equipped to provide bus signal priority. Furthermore, while signal priority enables the operation of rapid bus service with reduced stops and more liberal operating rules than local service, it is not solely responsible for the reduction of travel times reported. Buses receiving priority along the corridor travel approximately 20% faster than those without priority.

Capital costs for BSP average less than $10k per intersection, and $3k per bus. Total capital and labor expenditures for the project, exclusive of queue jump lane costs, are approximately $800K. VTA's experience with BSP is similar to that of AC Transit, LAMTA, Pace and other transit agencies across the nation. BSP is one of few cost effective tools available to public transit agencies that improve productivity without adverse consequences. BSP is a foundation element for VTA's extensive BRT planning effort, and it is likely that BSP will be a major component of transit operations industry wide in the near future.

This BRT priority scheme comes with dramatically lower capital costs and quicker implementation time than other mass transit options. Furthermore, as **driverless vehicles** come to dominate roadway traffic (see below), signal prioritization could also be provided for driverless vehicles that are platooning in groups. That scenario will not be viable for a decade or longer because the probability that two driverless cars will be in such close proximity in space-time to engage in platooning is only 10% when 30 cars out of a hundred are driveless (30%). However, when 70% of vehicles on the road are driverless, opportunities for platooning jump to over 50% - which will create a big demand for signal prioritization.

As more data accumulates comparing the travel time benefits of signal prioritization vs dedicated BRT lanes, increasing congestion is taking the shine off this opportunity. For example, travel times have degraded significantly along the El Camino corridor after signal priority was introduced (after an initial travel time benefit) due to increasing congestion. That travel-time degradation trend is expected to continue.

BRT with dedicated lanes on the other hand would cut travel times in half and result in travel times that are faster than driving. Sharing that dedicated lane with other HOV vehicles would more fully utilize a lane that otherwise might only move 1 bus with 50 riders every 5 minutes. Sharing that dedicated lane with other HOV vehicles might also justify conversion of a general purpose lane into an HOV lane – possibly a politically viable way to get dedicated lanes without the huge expense of adding new lanes.

Trade-offs
Mass transit (large vehicles with many passengers) with **on-line stations** can never escape the basic conundrum, i.e. more stops for more access but slower average speeds, or fewer stops with less access to increase speed. BART, LRT and BRT all suffer this trade-off. Fixed-rail mass transit systems seem more efficient because their corridors can move more people on a smaller right of way, but they don't substitute for a network with lots of access points. The many origins and destinations of people living in metropolitan sprawl are not confined to corridors. So, corridor stations should be well-supported by other transportation networks.

Fixed-rail transit with **off-line stations** (e.g. Caltrain Bullet Train and PRT) provide the time-saving and speed-increasing advantage of bypassing some/most stations. Likewise with standard bus routes and bus stops; lightly loaded buses bypass most stops. Eliminating all those stops between a rider's origin and destination dramatically improves average speed and reduces travel time.

Another big factor in door-to-door time is the percentage of time spent in active transport (driving a car, riding a bike, etc.) versus passive transport (BART, LRT, bus, Uber/Lyft, etc.). *Rule 14: People are willing to endure a longer commute if they can do something else during the trip.*

Driverless Vehicles: Disruptive Technology => Transport as a Service

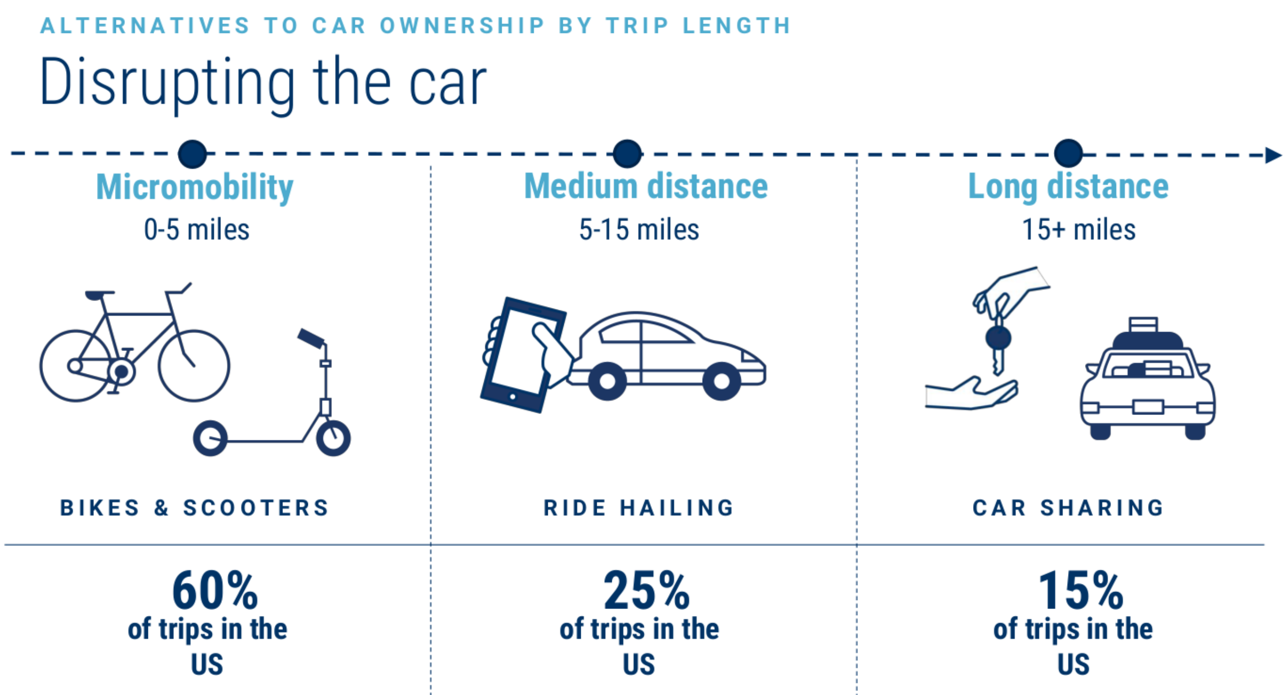
"We are on the cusp of one of the fastest, deepest, most consequential disruptions of transportation in history. By 2030, ... 95% of U.S. passenger miles traveled will be served by on-demand autonomous electric vehicles owned by fleets, not individuals, in a new business model we call "transport-as-a-service" (TaaS). The TaaS disruption will have enormous implications across the transportation and oil industries, decimating entire portions of their value chains, causing oil demand and prices to plummet, and destroying trillions of dollars in investor value — but also creating trillions of dollars in new business opportunities, consumer surplus and GDP growth."

That bold statement (and much of what follows) comes from Rethinking Transportation 2020-2030 - Disruption, Implications and Choices, a RethinkX Report by James Arbib & Tony Seba (page 6). They continue: "**The aim of this research is to start a conversation and focus decision-makers' attention on the scale, speed and impact of the impending disruption in the transportation and oil sectors.** Investors and policymakers will face choices in the near term that will have lasting impact. At critical junctures, their decisions will either help accelerate or slow down the transition to TaaS."

Although many decisions, they predict, will be driven by economic advantages, social and environmental considerations will also play a part (including fewer traffic deaths and injuries, increased access to mobility, and reduced greenhouse and toxic gas emissions). According to their report, adoption will start in cities and radiate outward to rural areas. Non-adopters will be largely restricted to the most rural areas, where cost and wait times are likely to be higher. As with any technology disruption, adoption will grow along an exponential S-curve.

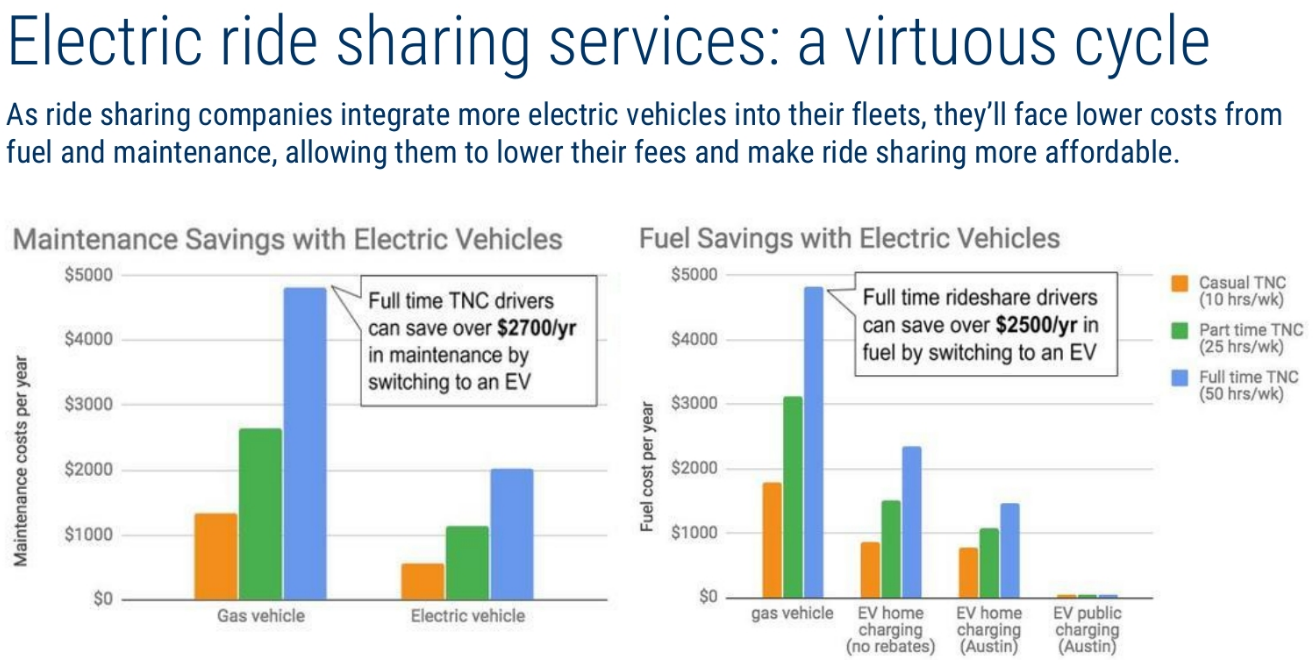
While the authors use the terms Autonomous Electric Vehicle and self-driving car, this paper uses "driverless" when referring to a fully autonomous vehicle (Level 5) which needs no human intervention at all — or even a steering wheel. Transport-as-a-Service (TaaS) providers (also known as TNC for transportaton network companies) will own and operate fleets of driverless vehicles providing passengers with higher levels of service, quicker rides and vastly increased safety at a cost up to 10 times cheaper than today's individually owned vehicles. These fleets will include a wide variety of vehicle types, sizes and configurations that meet every kind of consumer need, from delivering children to hauling equipment.

The start of this disruption will be the date that driverless vehicles are approved for widespread use on public roads. This date is dependent on both technological readiness and regulatory approval. Currently, 2021 seems the most likely year for the disruption point.



Author Tony Seba, a Stanford professor and guru of "disruption", points out that an internal combustion engine drive-train contains about 2,000 parts, while an electric vehicle drive-train contains about 20. All other things being equal, a system with fewer moving parts will be more reliable than a system with more moving parts. And that rule of thumb appears to hold for cars. In 2006, the National Highway Transportation Safety Administration estimated that the average vehicle, built solely on internal combustion engines, lasts 150,000 miles. Current estimates for the lifetime of today's electric vehicles are over 500,000 miles.

As Seth Miller points out, "The total cost of owning an electric vehicle is, over its entire life, roughly 1/4 to 1/3 the cost of a gasoline-powered vehicle. Of course, with a 500,000 mile life, a car will last 40–50 years. And it seems absurd to expect a single person to own just one car in her life. But of course, a person won't own just one car. The most likely scenario is that, thanks to software, a person won't own any."

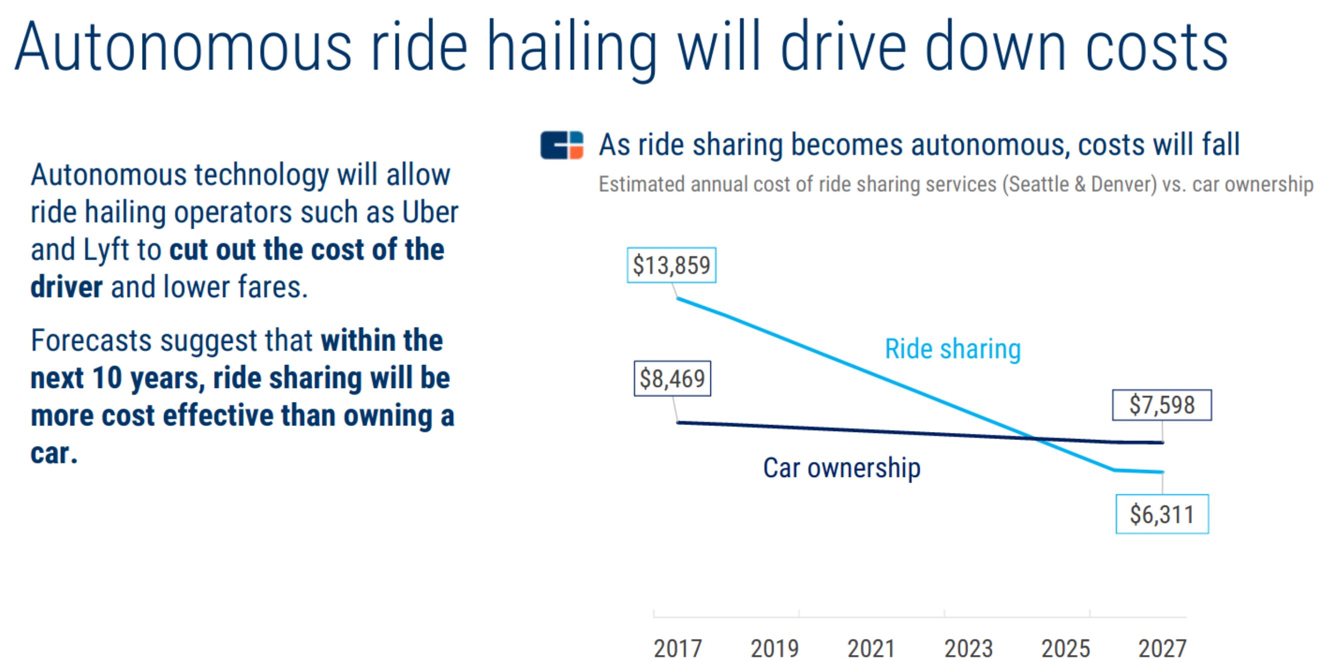


There is enormous latent demand for affordable transport-as-a-service rather than "I've got to do it all myself (buy a car, drive it, insure it, maintain it, park it, clean it, keep it from being stolen, ...)". Waymo has the opportunity to serve that fundamental consumer demand. By applying what they've learned in all of their testing to a commodity (existing cars like Chrysler Pacificas) using technology that obeys Moore's Law and a physical infrastructure (our existing roads and bridges), Waymo can provide a desperately needed mobility system that more effectively and responsibly uses what already exists (by increasing ride sharing of vehicles and reducing driver misbehavior).

The driver behind all this is simple: Given a choice, people tend to select the cheaper option. Seth Miller and RethinkX run the numbers in their report; here are some of their predictions:

- Self-driving cars will launch around 2021.
- A private ride will be priced at 16¢ per mile, falling to 10¢ over time.
- A shared ride will be priced at 5¢ per mile, falling to 3¢ over time.
- By 2022, oil use will have peaked.
- By 2023, used car prices will crash as people give up their vehicles. New car sales for individuals will drop to nearly zero.

- By 2030, gasoline use for cars will have dropped to near zero, and total crude oil use will have dropped by 30% compared to today.



This graph comes from slide 44 of "CB Insights: Disrupting the Car", a presentation by Rachel Binder, an intelligence associate at CB Insights covering the auto and mobility space. (Prior to joining the team at CB Insights, Rachel worked in equity research at Goldman Sachs covering retail companies.)

As a benchmark along the way, note that Waymo is set to grow its driverless vehicle fleet 100-fold having just placed an order for 62,000 Chrysler Pacifica minivans. This represents enormous growth for the company, which took delivery of its first 100 Pacificas in May 2016, when it formed a partnership with Fiat Chrysler Automobiles (FCA). Waymo's self-driving Pacifica minivans have been tested in 25 cities in the US (most of which are in California) and are currently on the road in five main cities: Atlanta, San Francisco, Detroit, Phoenix, and Kirkland, Washington. In November 2017, Waymo began test-driving its minivans on public roads in Phoenix without a driver at the wheel. They are just one of several companies obtaining permits to field driverless vehicles in California and other states.

Projecting forward Waymo's rapid growth, one expert (Alain Kornhauser) predicts: "Just think, if Waymo continues on its business plan without causing a crash, it means that their "driverless suite" really does work in its expanding geo-fenced areas. That dynamic evolution suggests that in September, 2020, there will be ~100,000 Waymo aTaxis serving ~5M trips a day throughout many medium density areas across a substantial part of the USA."

The End of Driving: Transportation systems and public policy planning for autonomous vehicles offers an alternative vision of the future reflecting a business-as-usual, continuation of current trends with a gradual, 40-year transition to fleets of driverless electric vehicles. The book's author concludes

"It may be appealing to argue that 'no one would sensibly own a vehicle,' but we insist that such an argument is not evidence-based and that no one has illustrated how to make that happen in reality and in a significant way." Clearly, Seth Miller and RethinkX would argue otherwise.

However, *The End of Driving* does provide a significant contribution to this conversation in Chapter 14: The End of Driving and Transit-Oriented Development. The Chapter Summary states "Transit-oriented development (TOD) is an appealing urbanist idea that has so far delivered important livability and walkable access to some transit stations in urban neighborhoods along particular corridors. However, in North America, the concept has generally failed at the metropolitan regional level to significantly constrain single occupant vehicle driving and boost transit system ridership. Until now, TOD has also failed to provide a pathway to affordable housing. This chapter presents two proposals that leverage automated Market 2 transportation systems [driverless vehicles] to address TOD effectiveness over the upcoming decades."

Their first proposes to use driverless vehicles to **increase the operational radius of the traditional TOD** location; the second leverages driverless vehicles to enable the deployment of many more, highly desirable, **TOD-equivalent locations** without the requirement for heavy, fixed-guideway transit.

Waymo-equipped Chrysler Pacifica minivan

Driverless vehicles are going to improve the quality of the lives of many people who will be able to use our existing road. However, adding driverless vehicles to satisfy latent demand (folks without a driver license) also adds dead-heading traffic (driving around empty to fetch the next rider). Some argue that driverless vehicles with current loading (1.1 passengers per vehicle during commute time) will not increase traffic congestion due to 1) the ability to safely keep shorter following distances from other cars (even without platooning), 2) finding more optimal routes, 3) reducing congestion-causing traffic accidents, and 4) reducing traffic waves.

Traffic waves emerge consistently when the vehicular density exceeds a critical threshold. Researchers have demonstrated experimentally that intelligent control of as few as 5% of vehicles is able to dampen these stop-and-go waves. These experimental findings suggest a paradigm shift in traffic management: flow control will be possible via a few mobile actuators long before a majority of vehicles have autonomous capabilities.

However, a recent study indicates that driverless vehicles without multiple riders are expected to increase congestion in congested areas (downtown) but not in uncongested areas (suburbs). Waymo's solution to the threat of congestion appears to be car-pooling, or more accurately, van-pooling. Their success in pricing TaaS to favor van-pooling over SOV driving will make the difference in congestion levels. Private companies and Type A Corporations will favor that level of congestion which profits them most. Publicly-owned fleets and Type B Corporations may price trips using other values.

Waymo announced on July 31, 2018, "Public transportation is an integral part of our cities, providing vital social, economic, and environmental benefits. That's why cities around the world invest significant resources to build and maintain public infrastructure—light rail, trains, and buses—that help people commute and move around. However, as cities grow and evolve, the 'last mile'—how people connect to public transportation efficiently, affordably, and safely—is one of the main challenges communities struggle to solve. **Waymo is partnering with Valley Metro**, the Phoenix area's regional public transportation authority, to explore mobility solutions that use self-driving technology to better connect travelers with the city's existing buses and light rail...."

Locally, Mountain View's Environmental Sustainability Task Force also gets it. Their June 2018 Sustainability Recommendations Report calls for a $100,000 investment in a

> "… transformative solution that leverages a transportation mode that is timely, familiar, and easy-to-use. The introduction of autonomous SOVs and small autonomous HOVs into the transportation mix is imminent. As this technology becomes commonplace, it is imperative that we encourage people to share these vehicles to reduce GHG emissions and alleviate critical pressures on traffic flows in the City. This strategy would require embarking on a new frontier of public transportation."

The RethinkX report anticipates a roughly 50% increase in passenger miles over the next 12 years due to latent demand from the 1 in 3 people who do not drive because they are too disabled, too young, too poor, or were too drunk. That increase in passenger miles will dramatically increase congestion in some areas unless some form of car pooling is successful. So, the Report anticipates a TaaS Pool "that entails sharing a vehicle ride with other people who are not in the passenger's family or social group — the equivalent of today's Uber Pool or Lyft Line. The vehicles delivering TaaS will be the same as TaaS Pool; only their usage (whether passengers are sharing) dictates what they are called. TaaS Pool will eventually grow in numbers of passengers to become more like today's public transportation."

Blurring the distinction between public and private transportation.
TaaS Pool will be cheaper and more convenient than most forms of existing public transportation. This will not only blur the distinction between public and private transportation but will also most likely lead to a virtual merger between them.

Michael Abramson proposes a segue that starts by supplementing public transit options with driveless vehicles.

> Specifically, the Waymo vehicles could be programmed to run every few minutes along the **existing** VTA bus routes using the **existing** stops to offer **free** rides to the public. In this mode, these minivans would serve as a fully autonomous, fast, and reliable public transit. Each of Waymo's Chrysler Pacifica minivans can carry 7 people, similar to average number of passengers per VTA bus, but the intervals between the vehicles would be smaller almost by the order of magnitude allowing for corresponding increase in throughput. Therefore, this Waymo-based network could become a backbone of the city's mass transit system.
>
> In addition, the city could provide a **free** Uber-like shuttle service, also using the Waymo vehicles, to connect any place in the city that is not within walking distance from transit network, to a closest node (station) in this network. School buses could also be rerouted to connect schools with closest bus/Waymo stops. This would make public transit easily

> accessible to anyone in the city. People still can use Uber or Lyft for direct point-to-point transit, but this would cost money, while public transit would be completely free.

Extending the TaaS concept to include other publicly-available transportation options is the goal of Helsinki-based startup Maas Global. (Mobility-as-a-Service – MaaS – is another term for TaaS and will be used interchangeably.) Their app, *Whim*, combines multiple transit systems in a single service. Users plug in a destination, then choose from a multitude of transportation options to get there: they can hail a cab, hop on a train or bus, rent a car or bike, and so on. The app handles route planning and payment. *Whim* was recently rolled out in two additional countries, Belgium and England. By 2020, Maas Global hopes to take the service worldwide.

Tesla – the Dark Horse MaaS Provider?

Tesla is exploring an alternative path to driverless cars providing MaaS. Having equipped all its cars with cameras, computer control and regular software updates, all Teslas on the road today have the potential to become vehicles in a MaaS fleet – offering Tesla owners the opportunity to earn money from their cars by allowing their use by the fleet manager when the car would otherwise be idle. After some recent first-hand Tesla self-driving experience, MaaS champion and Princeton professor Dr. Alain Kornhauser believes Musk may be on the right path. Kornhauser notes that it is plausible to believe that such a service could quickly scale to something like 2.5% of the daily U.S. rides – that would equate to a little more than 60% of today's public transportation ridership.

Driverless Vehicle Heaven or Hell?

Analysts and transportation advocates are no longer questioning whether self-driving cars, buses and delivery vehicles are going to a viable part of our transportation future. Instead, they are debating what that future should look like. The rapid development of self-driving, autonomous vehicle technology is opening a conversation about a wide range of mobility, health, and economic implications for marginalized groups like people of color, the poor, the elderly, and those with disabilities.

Greenlining Institute's analysis finds that optimistic scenarios for this transportation revolution – including reduced traffic, cleaner air and less space wasted on parking – won't come true without action by government to ensure that implementation of these technologies recognizes their broad impacts, especially the needs of marginalized groups. A transportation revolution that truly benefits all will need to center on FAVES: fleets of autonomous vehicles that are electric and shared, with rules designed to disincentivize personal autonomous vehicles and to promote affordability and access, along with fair labor practices in this new industry. Without such intervention, the autonomous vehicle revolution could lead us to transportation hell, with a growing mobility divide between haves and have-nots.

Greenlining Institute is a California-based think tank focused on racial and economic justice. Hana Creger is the author of the new report on driverless cars and freight vehicles that points out their potential to address inequality or further widen the economic gap between the privileged and the underserved. Creger argues that it's crucial that social justice advocates use this transition period to ask serious questions about how autonomous vehicles will impact low-income people, communities of color, people with disabilities and the elderly. For example, automation of transit not only eliminates living-wage jobs, it also removes the social services provided by bus drivers and other transit employees interfacing with the public. Creger sums it up this way: "For me, it's not enough that a car can drive itself; it should be making our entire transportation system better."

For now, self-driving cars appear to be moving in the right direction; the first self-driving permits issued to companies like Waymo and Zoox are for robot taxi services that pool riders, not for personalized vehicles for the wealthy. This seems to be the way forward. Treat driverless cars as public transit – whether publicly or privately owned – that can be programmed to deliver mobility to the public. They serve "anyone" and take customers anywhere at any time within their operational domain and, if properly managed, will allow, encourage and accommodate the sharing of rides by customers. Those shared rides will likely be at about the time that riders would otherwise be congesting the same roadways traveling by themselves, as they do now, in their own cars.

Policy Choices

The authors also predict that, as private and public transportation begin to merge, other revenue sources from advertising, data monetization, entertainment and product sales will **open a road to free transport**. Seeing it as a means to improve citizens' access to jobs, shopping, entertainment, education, health and other services within their communities, some municipalities may offer free TaaS transportation. To shrink the dramatic inequalities in our society, that road to free transport is worth exploring. Lowpriced tickets ($0.50 per ride) are already available to students using the Morgantown GRT to get to and from campus.

There are several public-policy pathways that can assist the development of TaaS in ways that optimize the benefits and mitigate the adverse consequences, including:

- Developing planning strategies for the reuse of unneeded transport infrastructure, parking lots and roadside parking spaces.
- Investing in public education campaigns to communicate the financial, social, health and environmental benefits of TaaS and to foster public acceptance and trust.
- Easing regulatory frameworks for the conversion of unneeded commercial garages to social and productive uses such as affordable housing, co-working spaces, art studios, in-law units, student housing and walk-up spaces.
- Increasing curb spaces for loading/unloading driverless vehicles at high-volume origin and destination locations.

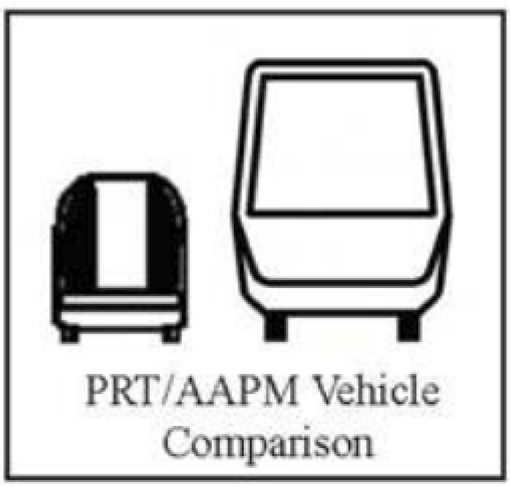
Potential of PRT/ATN

Automated Transit Networks (ATN), and the small-vehicle subset of Personal Rapid Transit (PRT), are emerging technologies that can help solve the related problems of congestion, dependence on foreign oil, and our planetary Climate Crisis. ATN/PRT offers clean, quiet, responsive public transit with automated non-stop service available 24 hours a day. In addition to these service benefits, PRT costs far less to build and operate than other transit options – and is safer than walking and cycling on nearby busy streets.

PRT systems could provide cost-saving substitutes for other costlier transportation projects while providing better service and less environmental impact. As a public transportation option, the fundamental shift is from and mass transit stations and big vehicles traveling along corridors with relatively few origins and destinations to small stations with car-sized vehicles traveling in networks between many origins and destinations - like the automobile! A quick introduction to the technology is this 3-minute video that shows how PRT could be used at the Microsoft campus. More videos that show and explain the technology can be found here: http://sunnyhillsneighborhood.org/crossing.html#videos

By delivering automated non-stop service 24 hours a day, PRT can provide a level of service far superior to conventional public transit options. PRT may be the simplest and least expensive means to add capacity in congested environments, and the most acceptable to end users and NIMBYs.

Morgantown GRT vehicles at a station



Ultra PRT / Airport Automated People Mover

As an example, consider the PRT-like system at Morgantown, WV, that has been operating since 1975. On a typical school day, 15,000 passengers will travel between five stations along an 8.7-mile track, riding in 71 self-propelled cars that travel at speeds of up to 30 mph. Although it cost $120M to construct, much of that was due to a poor design/build process. In today's inflation-adjusted dollars, the cost was $539M.

A crew of 55 keeps the system operating six days a week, working constantly to maintain the aging cars and guideway, sometimes scrounging for hard-to-find parts. The university spends $5 million annually for O&M. Thus, operating costs as a percentage of capital costs ranges from 4% down to 1% ($5M/$120M or $5M/$539M). On a per-mile basis, annual O&M cost works out to $575K/mile ($5M/8.7mile). Remember, those costs are for a customized system using old technology in a location that regularly freezes. While today's PRT capital costs should be lower, using the typical O&M costs of the transit industry (which range from 3% to 5% of capitals costs) is a good conservative starting point for estimating PRT O&M costs.

Rather than costing $62M per one-way mile (inflation-adjusted) as did the Morgantown system, today's PRT using smaller vehicles and guideways, modern sensors and controllers/computers, and a proven design can reduce capital costs by 75% to about $15M/mile. That estimate of one-way PRT includes stations and a moderate fleet of cabs, and is drawn from 12 written estimates plus a few guestimates that are outlined at http://sunnyhillsneighborhood.org/cost.html. Note in particular the first chart on that web page which shows the relationship between costs and both the installation environment and the number of cabs.

In addition to lower capital and O&M costs, passenger safety is increased. The NHTSA estimated that highway crashes cost society $230.6 billion a year, or about $820 per person. The Morgantown PRT maintenance crew is proud of the fact that of the 80 million passengers who have ridden on the PRT since its start, no serious injuries or fatalities have occurred. By comparison, auto deaths in the U.S. are trending down toward 1 fatality per 100 million vehicle miles traveled (VMT).

Surface area required at ground level is another factor to consider when thinking about transportation systems. An estimated 60% - 70% of urban space is dedicated to automobiles (both driving space and parking space). Some of that space could be reclaimed for public (or private) use if an elevated option like PRT absorbs many of the existing auto trips. Simply extending our current ground transport system with driverless vehicles keeps that asset locked up.

Although capacity of PRT corridor lines is relatively low compared with mass transit options, 3 PRT lines with an average of 1.3 passengers per vehicle running at 2 second headways (recommended spacing of cars on roadways) would carry 7020 riders per hour per direction – adequate for actual transit demand in most areas of the South Bay. If full loading of 4 passengers per vehicle were used as a measure of capacity, just 3 PRT lines running in the same direction could move 21,600 passengers/hour – comparable to some mass transit technologies. And while platooning of driverless vehicles appears to be a decade away, platooning of PRT cabs can be accomplished with current technology by simply reducing the headways. PRT also provides more stations near more people and non-stop transit to stations nearer their destination thus ensuring a quicker door-to-door trips than mass transit options.

Pedestrian Over-Crossings (POCs) Obsolete?

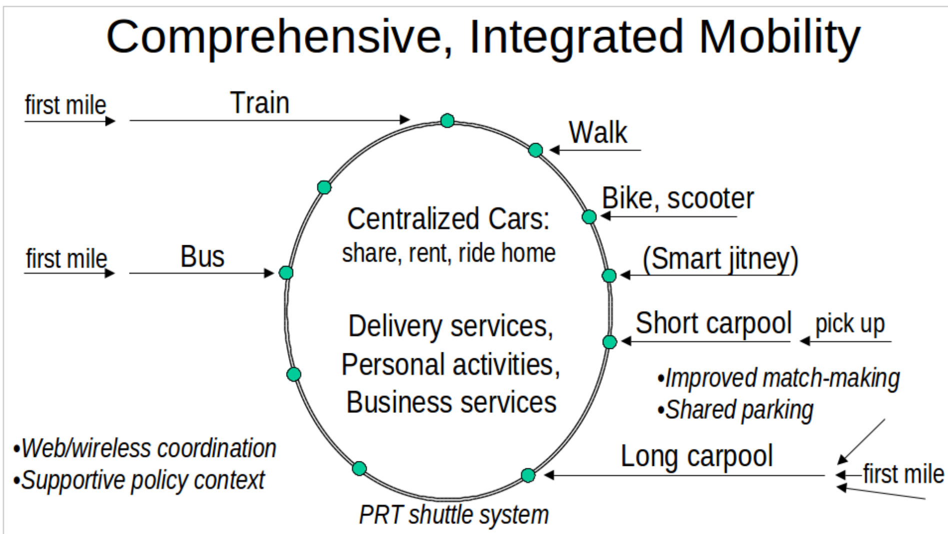
As mentioned above, Pedestrian Over-Crossings (POC) cost about $150/mile to cross creeks, roadways, railroads and other barriers. Using standard steel-and-concrete bridges has become increasingly costly in terms of money and time. Finding an alternative, less expensive technology to bridge barriers will support all transportation alternatives, not just cyclists and pedestrians.

As an alternative to standard steel-and-concrete POCs, consider using a technology that simply carries people from one side of a barrier to the other, like a horizontal elevator or a ferry. Although PRT technology could be used (at a cost of $30M per bi-directional mile), so could a number of amusement park ride technologies that are priced similarly or lower. The primary reason POCs cost 5 times as much per mile as PRT is that POCs must accommodate a full load of people side-to-side and end-to-end. Holding up that much weight requires a lot of strength (which generally means a lot of expensive stuff). Controlled-access technologies like PRT that only allow a certain number of people and vehicles on a span at any one time can keep the load down, and thus keep the need for strength (and stuff) down.

For example, consider the possibility of using PRT to provide a shuttle service across Montague Expressway in Milpitas. Currently, a $14M POC is planned to connect the BART parking garage to the neighborhood on the north side of Montague. Using an estimate of 200' to cross Montague Expressway, doubled for 2 one-way tracks, and then doubled again to allow for turnarounds and stations adds up to a need for 800' of guideway, or only 0.15 mile (800/5280). Based on the $15M/mile estimate, the anticipated cost of 0.15 mile of PRT is $2.25M. Although most of the $14M POC cost will come from transit agencies, the anticipated cost to the City of Milpitas is still $4.5M. By using shuttle technology, a savings to the City of $2.25M is possible. Or, we could say that a POC will cost the City of Milpitas twice as much as a shuttle.

If such a PRT ferry or shuttle proves cost-effective, it can be replicated as a substitute for POCs across the country. It could also make currently-too-costly crossings more affordable, and therefore more likely to be built and used sooner. Given the extensive need for barrier crossings in Santa Clara County, further investigation of alternative technologies to shuttle people across them is warranted.

PRT Synergy

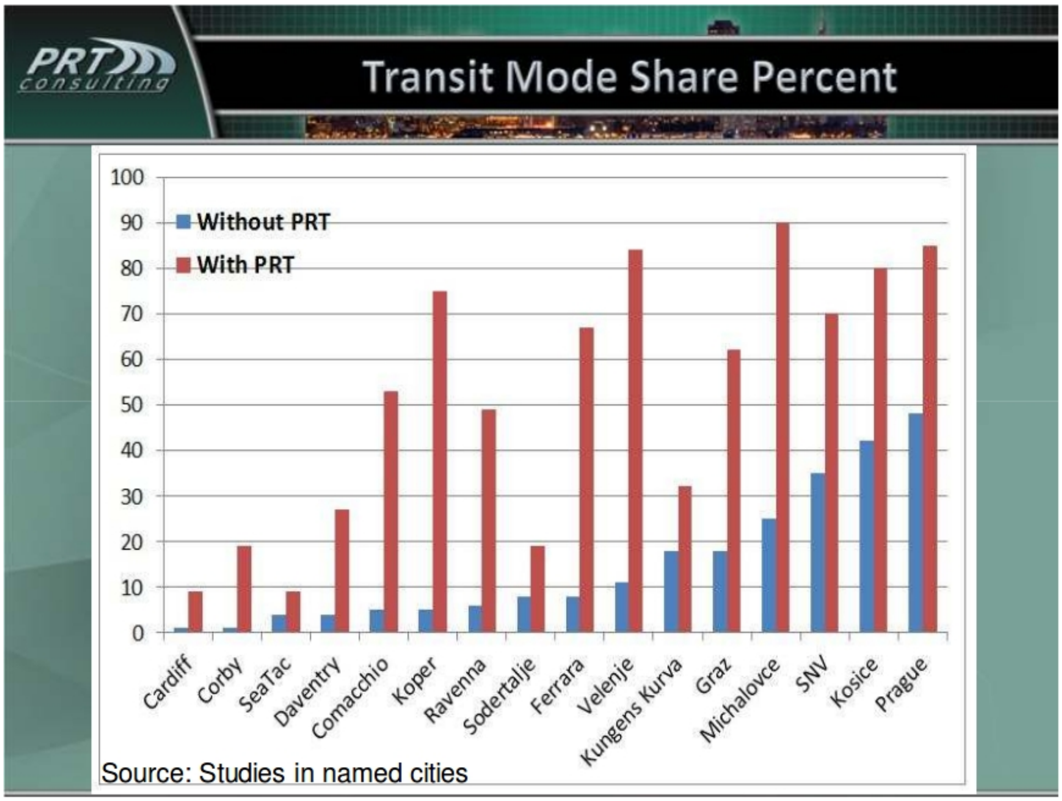


The potential of PRT to reduce single-occupancy vehicle (SOV) driving is striking. This abstract from a 188-page peer-reviewed study indicates that the SOV rate at a high-tech job center could be cut in half:

> ABSTRACT: A five-mile, $50M Personal Rapid Transit (PRT) "shuttle" system is proposed for Palo Alto's Stanford Research Park (SRP), complementing and significantly increasing the attractiveness of commuter rail, carpool, vanpool, bicycle, and bus commutes for the center's 20,000 employees. ...
>
> A complex travel demand analysis was conducted on a sample of suburban employees, of which 89% drive alone. When presented with a hypothetical Year 2008 commute alternative scenario, where PRT solved the "last mile" problem and new mobility services solved specific objections, drive alone commutes dropped to only 45%. Extrapolating to the entire office park, 6,600 cars per day are removed, freeing 50 acres of parking for reclamation, conservatively worth $150M. It appears possible to eliminate traffic congestion and air pollution without lifestyle sacrifice -- a result consistent with the Bush

> Administration's energy policy philosophy. ... The model for Palo Alto plausibly translates to other job-rich major employment centers. (http://www.cities21.org/silver_bullet.htm)

While potentially cutting SOV driving in half, PRT combined with other public transit modes has been predicted in many studies to dramatically increase transit ridership as shown below.



What other transportation options or combination of options being proposed proposes such a dramatic reduction in SOV rates and increase in transit ridership? To a large degree, this 2003 study anticipated TaaS. Today, implementation could be easier and more effective than 15 years ago. As mentioned above, web/wireless coordination of transportation services is being developed by Maas Global. Their app, Whim, combines multiple transit systems in a single service. With most of the technology already developed, what is needed now is a "supportive policy context" that encourages TaaS and provides cross-system payment coordination.

PRT Test Case

By the end of 2020, a major transit hub at the southern edge of Milpitas will offer access to BART, LRT, bus and TaaS (Uber/Lyft) along with provisions for cyclists and pedestrians. Unfortunately, 1) access to that cornucopia of transportation options is difficult, and 2) already-bad traffic congestion in the Milpitas Transit Area will worsen as the expected 7000 homes are occupied and the BART station starts operating (12,000 daily riders).

An advanced transit circulator has been proposed to help mitigate both problems. (See http://sunnyhillsneighborhood.org/first-loop.html) Using small electric cabs on an elevated guideway, residents from 7 separate housing areas could easily access the BART station, new elementary school, Great Mall, and three city parks without using a car or walking/cycling circuitous routes on high-volume, high-speed roadways.

As noted in the section above, driveless vehicles without multiple riders will increase congestion due to latent demand (by people without a driver license) and dead-heading (driving around empty to fetch the next user). For most of the area in the South Bay, congestion is not a big problem – but it is in the Milpitas Transit Area. Thus, moving some of that area's transportation demand into the third dimension where there is space for it (e.g. elevated PRT) will become even more important with the opening of BART, the rapidly increasing transit-area population, and soon-to-arrive driverless cars.

An initial dual-loop PRT system is proposed to include 4 miles of guideway connecting 12 stations for a cost of $60M (4 miles x $15M/mile), about the cost of Milpitas City Hall in inflation-adjusted dollars. O&M would run between $0.6M and $1.8M per year ($60M x 1-3%). To re-coup that much from the farebox would 1) be something that no transit system in the Bay Area accomplishes, and 2) require 5000 trips per day charged $1/trip. Such a project would help validate costs and benefits.

If the dual-loop project is successful, then the transportation picture for many United States metropolitan areas could change – rapidly! If PRT is adopted at the rate the electric trolley was over a hundred years ago, investment in this project could spark a wave of systems across the country within ten years that could generate benefits totaling tens of billions of dollars.

Appropriate Application of Technologies

Having reviewed various factors in our transportation equation, we come to the critical question: What combination of options makes sense for this defined area?

If, over the course of twenty years, untold millions of dollars are spent on a public transit system, and the growth in ridership has not kept pace with the growth of the population base being served, that is a system in decline. Before continuing along the same declining path, transportation agencies and experts owe an honest solution to this equation:

$$\text{Value} = \boldsymbol{f}\,(\text{performance, price, benefits, impacts}) \text{ vs. alternatives}$$

In plain English, the value of a transportation option is a function of various factors, and must be compared with the alternatives.

> Performance - of both the transportation option itself as well as the performance of the existing transportation network within which it is embedded. For example, when a newly-installed LRT line attracts most of its riders from a bus route(s) that already served that area, only the additional increment in ridership is a performance increase for the network. Given that traffic

congestion is estimated to cost Silicon Valley approximately $50M per day, reducing that congestion is also a high-value performance factor.

Price - of both capital investment and O&M. It may be prudent to also include any anticipated replacement/disposal cost at the end of the useful life of the transportation option. Congestion pricing (to reduce demand), although not normally thought of as a transportation option, can produce results equivalent to major capital investments (to increase supply) in reducing congestion. By offering employees $5/day as a transit subsidy and then charging $5/day to park yields a substantial (15-50%) reduction in SOV (single occupancy vehicles). Another capital-free option is telecommuting which already keeps more people out of cars than VTA's average weekday daily LRT ridership of about 33,000 passengers.

Benefits - for both the individual and the society/community. **Individual benefits** include convenient access, commute time reduction, and ride time not dedicated to controlling the vehicle. Increasing the number of stations increases the likelihood that one is conveniently located close to the user's origin and destination points. Commute time is reduced when 1) number of transfers and transfer times are reduced, and 2) stations are widely separated or off-line (so users do not stop along the way). Time spent riding in an automated or chauffeured vehicle is available for other activities. **Societal benefits** include increasing transportation equity and reduced CO_2 emissions. (Transportation pollution ticked up another 2% in 2016 due primarily to increased driving). Local economies are benefited when the primary cost of a daily commute (average round-trip commute miles X $0.31/mile to operate a car) is redirected from transnational oil interests. Economic benefits for nearby businesses could result from the increased mobility by making it easier to find and retain both customers and workforce; and as businesses benefit, cities can expect higher revenues.

Impacts - include environmental damage, visual impact, and auditory intrusion. Environmental impacts of a transportation option vary with resources used to build (smaller is generally less resource intensive) and operate it (electric drive and off-the-shelf repair parts are less expensive).

Various transportation-oriented organizations create their own value statements that are variations on the above. The addition of a transportation option to the existing network of transportation options should be designed to both serve the immediate area, but also to improve functioning of transport options in the surrounding area. For example, building a bike/ped crossing of a barrier not only serves the immediate area, but also the bike network connected to that location – extending several miles from that crossing.

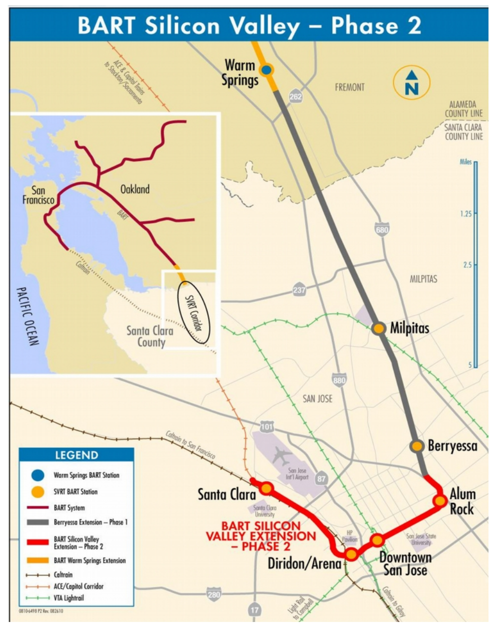
Appropriate application must also consider whether private money is used to build the system, and how the ROI is distributed. Keeping both in the public realm as has been done for most transit systems, and creates even more value for the public if a positive ROI can be achieved.

In the Conclusion below, the Rules of Thumb listed previously are gathered together. They are useful in choosing between transportation options for any particular application.

Transportation Option with Questionable ROI

While the idea of BART around the Bay is attractive from a marketing viewpoint, the actual value of BART Extension Phase II (BART Burrow connecting Berryessa station to Diridon Station) is questionable. The price tag validates Rules 1 and 2 by being bigger and under-grounded, thus leading to a high-dollar price ($4900M for 6 miles and 4 stations, $800M/mile). Unfortunately, the projected demand (50K pax/day) is far below its capacity (50K pax/hour). This overcapacity is very expensive.

While performance of the existing transportation network is enhanced by the BART connection with Caltrain, the physical separation of the two systems combined with the scheduled (rather than demand) service on both options leads to transfer delays (reduced convenience). For BART riders heading East from downtown San Jose, the transfer to another mode is eliminated. However, due to the limited number of stations along a corridor route, most users will not find stations conveniently located. Convenient access to those few stations will be needed by riders to avail themselves of the benefit of a transfer-less ride between downtown and the East Bay BART corridor.



Actual service level (convenience) of the BART Burrow is limited by the number of stations, a 20-minute headway schedule, and a loading platform located 75 feet underground. There is also concern the newly-installed BART line will derive many of its riders from bus Route 22 that parallels its corridor. BRT service along that corridor also competes for riders.

Impacts could be more than anticipated during construction of a large-bore subway in an area with a high water table. While the visual and auditory (steel wheel on steel track) intrusion are limited to BART users, construction will require massive resources and significant disruption to local businesses. Although operable with renewable energy, overall energy efficiency per passenger-mile is limited by the many off-peak hours when the heavy trains carry few passengers.

One could argue that a commuter rail project can be justified only by the extent to which it cost-effectively reduces traffic congestion and increases transit ridership. Neither seems likely for this BART segment. If zero-based budgeting were applied to the BART Burrow, would it continue moving forward? How does it compare with alternatives today? And what other transportation options (aka **opportunity costs**) could be developed using just half of the $4900M price?

Promising ROI Example

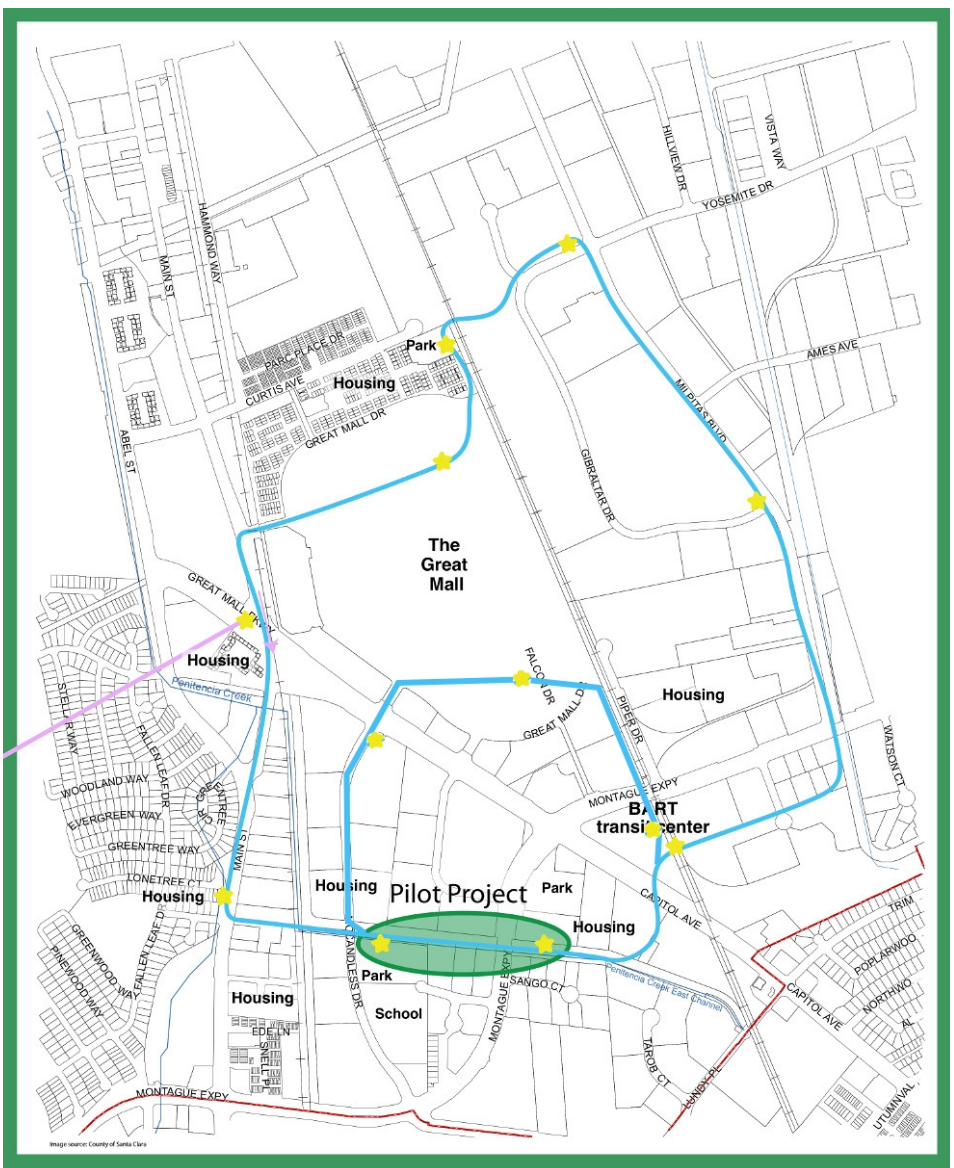
Nearly all the housing in the entire Milpitas Transit Area is separated from the BART transit hub by huge roadways (Great Mall Parkway and Montague Expressway). Although both are walkable/bikeable, most parents would not want their children on or around those roadways unless absolutely necessary. Even for experienced cyclists, these roads are not convivial and inviting – thus another impediment to getting people out of their cars. Other barriers to travel in the Transit Area include the BART tracks, a separate set of railroad tracks, and a creek. Access by motor vehicle will likely remain the dominant way to get to the transit hub, especially for residents living in the northern half of Milpitas. Unfortunately, access by motor vehicle (whether self-driven or driverless) can be problematic at certain times of the day due to the heavy congestion between I-680 and I-880 – congestion that will likely worsen as driverless vehicles become common, thousands of new residents arrive, and BART starts operating.

In such a congested, high-density area, it makes engineering sense to move to the 3rd dimension by considering technologies that use elevated guideways such as Personal Rapid Transit (PRT), Group Rapid Transit (GRT), and Automated People Movers (APM). With an estimated daily ridership of 12,000 passengers on BART and perhaps a similar number for all the other transit hub options combined, the higher capacity of a GRT or APM option is an unnecessary expense (Rule 1: bigger costs more). PRT capacity is adequate to serve the demand.

PRT is easy to route due to tight turning radii, potentially steep gradients (10% or more), and elevated guideways. Thus, destinations (stations locations) can be chosen first, and then routes planned to connect them. In conventional fixed-rail projects, routes are often the determining factor with station location secondary. Most people familiar with the Transit Area would agree that stations are needed to serve the BART station/transit hub, the Great Mall, and the elementary school. One proposal would create a [dual-loop PRT system](#) to serve these 3 locations along with parks and several housing areas.

Two variations on that dual-loop proposal begin with a smaller pilot project. One version simply creates a pinched-loop crossing over Montague Expressway while the other starts with a 1.5-mile loop. Both variations anticipate expansion into the dual-loop system pictured below. In addition to the 3-mile loop, both the 1.5-mile Mini-Loop and the Montague crossing (marked as "Pilot Project") are shown in the map below.

A dual-loop PRT system overlaying the current transportation options would enhance the utility of all of them while also providing convenient access to/from the transit hub for



everyone in the area. In addition to enabling pedestrians, cyclists and other last-mile commuters, the loop would also provide a way for cyclists to cross the north-south railroad tracks that divide the city, thus avoiding the only two current options in the souther half of Milpitas – Montague Expressway or Hwy 237/Calaveras Boulevard. Bus routes and TaaS vehicles could be scaled back as PRT serves more people more conveniently in the area. Thus, performance of both this transport option and the surrounding transportation network are likely to be high. Whether traffic congestion will be reduced is yet to be seen.

Cost of PRT, both capital investment and O&M, is competitive to other options as outlined above in *Potential of PRT/ATN*. Also, a planned $12M pedestrian over-crossing of Montague (at the "Pilot Project" site) would not be needed.

The dual-loop PRT system promises individual benefits of convenience, commute time reduction, and free time. In addition to on-demand, no-wait cab availability at 12 conveniently-located stations, non-stop/non-transfer rides to any of those stations reduces door-to-door time – often more so than driving. The few minutes riding PRT are available for use by the rider(s). Societal benefits include increasing transportation equity and reducing CO_2 emissions.

Environmental impacts are small due to fewer resources to build and operate. Visual impacts are far less than other fixed-rail transit options due to a guideway cross-section as small as 3 feet by 3 feet. Auditory intrusion of cabs rolling along the guideway are far less than cars due to light weight cabs, electric drive, and rubber tires running on a smooth surface.

$$\text{Value} = \boldsymbol{f}\,(\text{performance, price, benefits, impacts}) \text{ vs. alternatives}$$

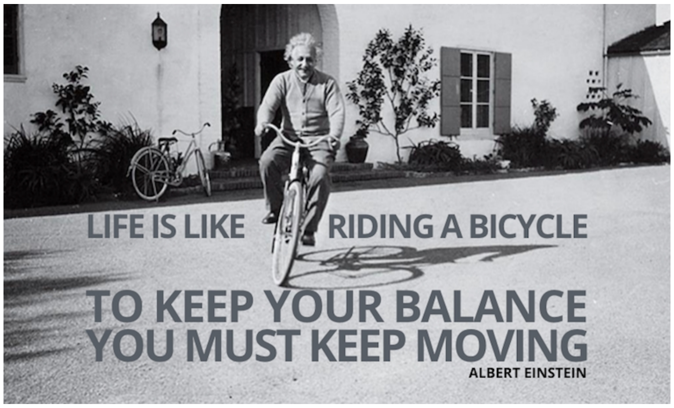
Various factors contribute to the service level (Value) of any particular transportation option. In plain English, the Value of a transportation option is a function of various factors, and must be compared with the alternatives. The value of a PRT loop serving the BART transit hub appears to be high, but must also be compared with other alternatives to confirm that assessment.

The comparison chart in Appendix A from PRT Consulting provides an overview and comparison of many of them. While that chart and others are somewhat subjective, they all indicate that PRT offers significant advantages over other transportation options.

LoopWork's Vision

LoopWorks' Mission Statement: To Provide high quality, carefree, in-town, elevated travel at no cost for Milpitas residents and visitors that is clean, safe, climate friendly, efficient and will provide stable employment.

From that Mission Statement follows a mobility model that naturally focuses on community-owned transportation solutions that rely on renewable energy and provide efficient, very low cost, universally accessible and equitable options for residents and visitors.



Santa Clara County has an SOV (single-occupancy vehicle) problem. An estimated 76 percent of workers drove to work alone in 2012-2016, and 10 percent carpooled. By comparison, public transportation (excluding taxicabs) delivered 4.1%, while telecommuting accounted for nearly 5%. That high SOV of 76% is creating demand for roadway that can no longer be met efficiently. HOV lanes are attempts to reduce the SOV rate. Other approaches appear more effective as reported in *Sustainable Suburb Silver Bullet: PRT Shuttle + New Mobility Halves Solo Commutes*. To a large degree, this 2003 study anticipated TaaS. Implementation today could be easier and more effective than 15 years ago.

As stated in the Executive Summary of the June 2018 report of Mountain View's Environmental Sustainability Task Force 2 (a Council Advisory Body of 28 appointed community members who live or work in Mountain View):

> A holistic suite of actions has been demonstrated to be effective in encouraging people to switch to alternative modes of transportation: restrict parking, make transit free and convenient, design streets for bikes and pedestrians, and extensively encourage alternative commuting practices through outreach. These actions all work together. Taken separately, they are unlikely to have the necessary impact. Together they can be transformative.

As part of the Milpitas community, LoopWorks is also concerned about affordable housing, living wages, and cultivating the commons. Housing without parking facilities costs less than housing with, so one can see as a trend to be encouraged the imminent arrival of TaaS that provides people with transportation without the need for having a car.

Like so many past introductions of automation, people will lose jobs as driverless electric vehicles – whether on the ground or elevated – become a significant factor in our transportation picture. Some are starting to urge decision makers to respond to the loss of jobs by pressing for national legislation that provides government-funded jobs to all who want to work in addition to providing a universal basic income.

The commons – infrastructure that community members use in common – should be community owned, whether through an elected governmental body or an elected community-based organization operated for community benefit. Thus, decision makers are urged to create a "supportive policy context" that encourages TaaS and provides cross-system payment coordination.

Ultimately, the vision of a TaaS future is supported by the LoopWorks dual-loop PRT project which could inspire rapid and widely-implemented advanced transit that dramatically reduces CO_2 emissions from the transportation sector of societies.

Issue Areas NOT Addressed

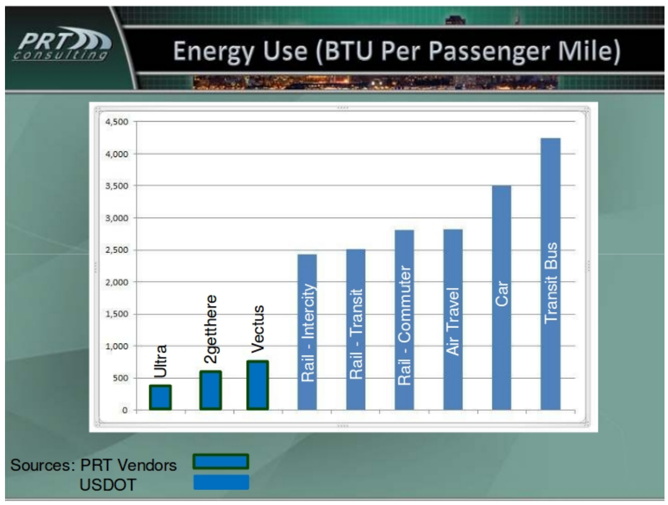
Urban Air Mobility (UAM), also known as On-Demand Mobility (ODM), portends to be a safe and efficient system for air passenger and cargo transportation within an urban area that will be enabled by quiet and largely automated aircraft. The main advantages of such a system are speed and flexibility. UAM systems have similar performance profile to elevated PRT and offer many of the same benefits. The timeline for adoption of the UAM includes large-scale demonstrations of UAM in the early 2020s, and by 2030 the UAM systems may become widespread. See Appendix B.

Rocky Mountain Institute (RMI) believes **behavioral economics** (BE)—the study of how we make decisions based on emotion and biases—can identify underlying barriers to change and unlock the full benefits of mobility alternatives. RMI's new paper, Mapping Incentives to Change, discusses how planners can encourage positive commuting change through commuter scoring programs and other means informed by BE. RMI's mobility team has been focused on BE in order to move us more quickly toward a new, shared, electric, and autonomous mobility paradigm that benefits people and our planet.

Although not a big problem in the Bay Area, **what to do with old transportation infrastructure** is a growing issue across the country. Do we repair, or demolish and replace? At what cost financially and environmentally? Since some PRT designs are simply bolted together from manufactured parts, the downside risk in building them is low. After a year or two of use, a City may decide to replace their PRT technology with another type of advanced transit. After unbolting the system from its footings, the parts could be sold off to another municipality.

What actual impact does transit have on congestion? Does it serve to simply mitigate a bad situation by preventing vehicle-hours of delay from growing faster than without transit? Or is there a possibility of actual reduction? At what cost?

Comparison of gallons of carbon-based fuel per passenger-mile are warranted given our state's efforts to reduce CO_2 emissions and the urgency of Climate Chaos. Computing and comparing numbers can be tricky. For example, national bus average occupancy is 9, which for a 50 passenger bus is 0.18 (18%). For private vehicles assuming 5 seats available and just the driver yields an occupancy rate of 0.20 (20%).



History shows that **cost overruns** are likely in Megaprojects like HSR and the BART Burrow.

Automation in the public transit sector not only means the loss of many living-wage jobs, but also the social-service functions that bus drivers and others provide to the public. It is time for a national conversation about providing citizens with a universal basic income, or better yet, a guaranteed living-wage job for all who want it (estimated at 96% of able working-age people).

Traffic congestion in Santa Clara County has dramatically worsened over the past several years largely due to **private companies** taking advantage of the physical and intellectual infrastructure in our area to **create more jobs without creating more housing and transportation infrastructure**. For example, congestion-related delays during weekday commute periods around the region increased more than 80 percent over the 1.9-minutes-per-commuter-per-day figure registered in the recession year of 2010. Although some corporations have contributed their own corporate buses to the solution (for their employees only), not all employees take the bus.

The **political challenge of reallocating resources** to add more capacity for bicycles, pedestrians, and transit - which is likely to face resistance. The resistance to VTA's proposed Bus Rapid Transit on El Camino Real is a recent example

Conclusions

By looking at transportation options in the South Bay through various lenses, we can deduce some general rules to guide our technology choices in the future.

Rule 1: Designing a system that works well for people goes a long way toward a system that works well to transport stuff.
Rule 2: Corridor systems with on-line stations have fewer that are farther apart to allow for higher speeds.
Rule 3: Network systems like roadways generally run at lower speeds and serve to connect many origins with many destinations in a defined area.
Rule 4: Networked systems come in two flavors, those that require a transfer to another vehicle and those that don't.
Rule 5: Maximum capacity on a corridor is rarely achieved, while the average loading is less than half of theoretical maximum capacity.
Rule 6: Adding parallel lines to a low-volume transit network adds capacity that can eventually exceed high-volume corridor transit throughput.
Rule 7: Low-capacity transit like PRT can use multiple stations with multiple berths – all operating in parallel – to achieve high capacity.
Rule 8: Trips are multi-modal.
Rule 9: Switching modes or vehicles can be quick and easy unless the transfer requires a wait – largely because waiting time seems longer to people than it really is.
Rule 10: The more stuff required to build a transportation option, the more it will cost.
Rule 11: A transportation option that costs X dollars at ground level, will cost 2X dollars when elevated, and 3X dollars when under-grounded.
Rule 12: Capital costs for a technology vary widely depending upon constraints.
Rule 13: Dirt costs a lot in our area.
Rule 14: People are willing to endure a longer commute if they can do something else during the trip.

These rules, when applied to the South Bay Area, lead to these guidelines:

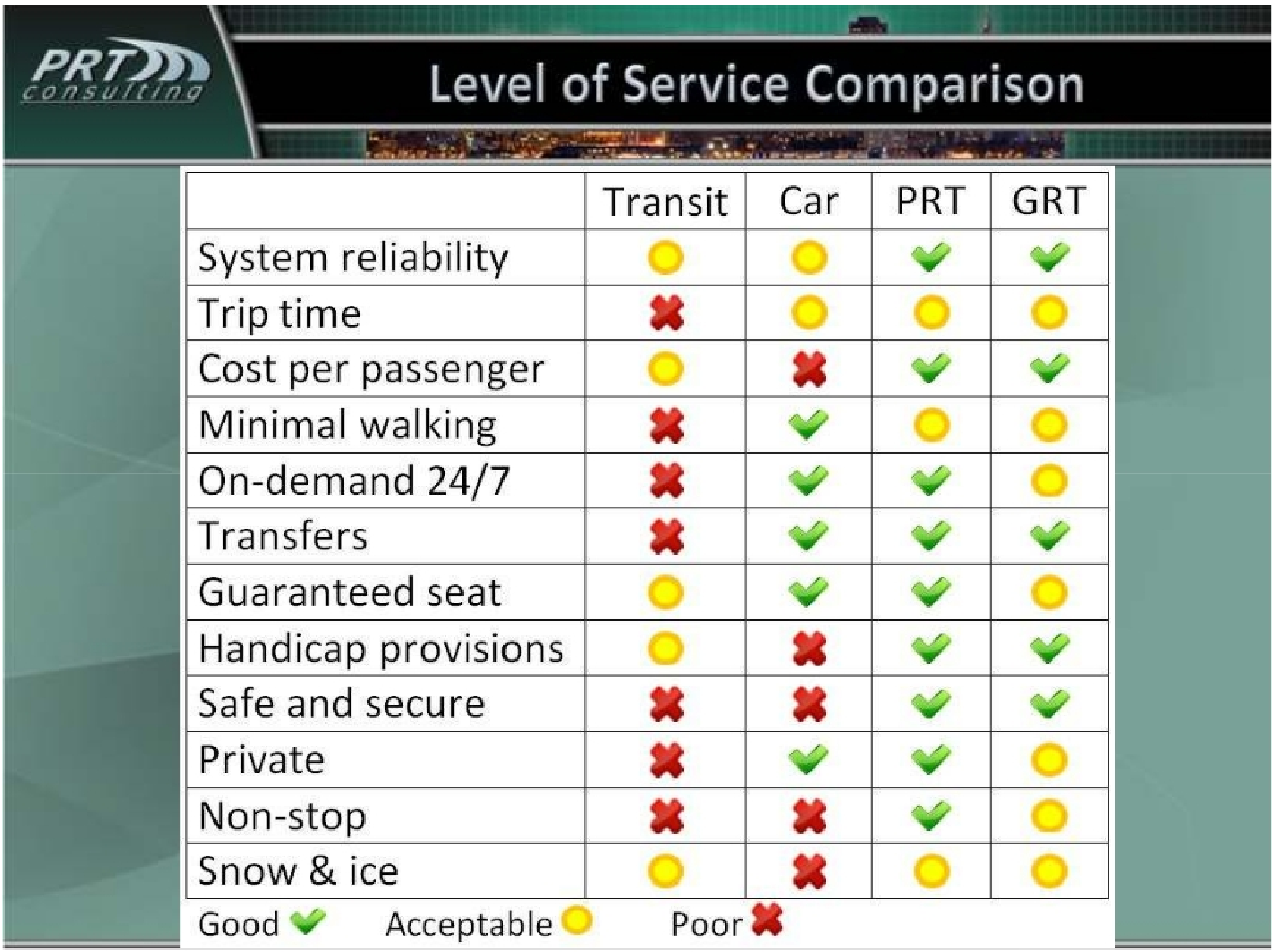
- Prioritize networked systems over corridor systems. Due to the car-facilitated sprawl of the South Bay Area, networked system work better in our area for most transportation needs, while higher-speed corridor systems serve for longer links.
- Balance capacity to demand. Due to low-density sprawl, higher-capacity transit options are rarely needed.
- More no-wait connections is often better than fewer connections that require waiting.
- Reducing door-to-door time is more important than the speed of any particular link.
- When evaluating ROI, focus on the value to the entire network of options provided by the particular transportation option under consideration.

These technologies merit further research and development:

- Synchronize signals to enable BRT-Light without dedicated bus lanes.
- Encourage fleets of driverless vehicles to provide Transport as a Service (TaaS).
- Pursue the strategy laid out in the Silver Bullet scenario so we can reduce SOV use by 50% in certain instances.
- Develop the potential of PRT/ATN (Personal Rapid Transit / Automated Transit Network) to bridge barriers, mitigate traffic-congested areas, and competitively provide TaaS to a wide-area network.

Appendix A

Various factors contribute to the service level of any particular transportation option. The comparison chart below from PRT Consulting provides an overview and comparison of many of them. While this chart (and others) are somewhat subjective and lack supporting data, the general consensus appears to be that PRT offers significant advantages over other transportation options.



	Transit	Car	PRT	GRT
System reliability	●	●	✔	✔
Trip time	✖	●	●	●
Cost per passenger	●	✖	✔	✔
Minimal walking	✖	✔	●	●
On-demand 24/7	✖	✔	✔	●
Transfers	✖	✔	✔	✔
Guaranteed seat	●	✔	✔	●
Handicap provisions	●	✖	✔	✔
Safe and secure	✖	✖	✔	✔
Private	✖	✔	✔	●
Non-stop	✖	✖	✔	●
Snow & ice	●	✖	●	●

Good ✔ Acceptable ● Poor ✖

PRT Consulting offers a comparison of transportation options in the 10-page article SOME 21ST CENTURY TRANSPORTATION SOLUTIONS: A COMPARATIVE ANALYSIS by Peter J. Muller, P.E., President, Advanced Transit Association, pmuller@prtconsulting.com

Appendix B

-------- Forwarded Message --------
From: Michael Abramson <abramson53@gmail.com>
To: Rob Means <rob.means@electric-bikes.com>
Cc: Rob Means <Rob@meansfordemocracy.org>
Subject: Re: White Paper on South Bay Transportation Options
Date: Sat, 18 Aug 2018 21:56:11 -0700

Hi Rob,

I enjoyed reading your document. It's well written and covers a wide range of relevant considerations. I agree with most of your analysis of different options and proposed solutions, but, as you asked, I was also looking for errors and omissions and found some.

The biggest omission seems to be that you didn't even mention the Urban Air Mobility (UAM), known also as On-Demand Mobility (ODM), a safe and efficient system for air passenger and cargo transportation within an urban area that will be enabled by quiet and largely automated aircraft.

The main advantages of such a system are speed and flexibility. The passenger aircraft can be faster than any other transportation mode, except maybe the HSR. The UAM requires minimal ground infrastructure: parking lots or the roofs of some buildings can be adopted as helipads.

The UAM systems have similar performance profile to elevated PRT and offer many of the same benefits:

- small occupancy vehicles with high speed, frequent arrivals/departures, and routes/destinations controlled by passengers
- vertical separation from ground traffic
- fully autonomous operation
- low construction and O&M costs
- will operate as TaaS similar to Uber model (it's not accidental that Uber has created the Uber Elevate division).

The timeline for adoption of the UAM is similar to what is expected for driverless ground vehicles. First large-scale demonstrations of UAM are planned for early 20s, and by 2030 the UAM systems may become widespread.

The main technical challenge to UAM and driverless cars is also the same: both need a robust Detect-and Avoid (DAA) capability (this is my area of expertise: I work in the modeling and simulation group supporting NASA research on DAA systems of unmanned aircraft). In some respects, the problem is easier for UAM: aircraft can maneuver in three dimensions and doesn't need to deal with pedestrians and bicyclists. However, the higher speeds require sensors with longer range. The aircraft used in UAM is expected to be equipped with ADS-B or other similar systems that enable sharing information about its positions. However, such systems may have insufficient accuracy and can be compromised by technical glitches or by deliberate jamming or spoofing. For this reason, the aircraft must also be equipped with so-called "non-cooperative" surveillance systems, such as radars or electro-optical sensors. The progress in development of low cost, size, weight, and power sensors and in DAA algorithm development for both driverless ground vehicles and autonomous aircraft is so fast that it leaves little doubt that the problem will be solved within next few years. There are also regulatory and psychological barriers, but once people see safety and benefits of new technology, the public acceptance will follow.

Yet, the UAM is not a silver bullet. It has its problems and limitations. The UAM systems will not be allowed to operate in restricted airspace around airports and other sensitive objects. Also, all aircraft is affected by winds (not a big problem in Bay Area, but still a problem).

In principle, the UAM can be used at short distances and even serve as a "first mile" option in sparsely populated areas. However, a "sweet spot" for UAM systems is the range of distances characteristic for large metropolitan areas. If you want to go from one part Mountain View to another, you will most likely find ground transportation more than adequate. However, if you want to get from Mountain View to San Jose or San Francisco in rush hour, especially if you don't live close to one of Caltrain stations, you can find the UAM a viable option.

No, the UAM will not replace the cars, and it will not make the PRT systems obsolete in foreseeable future, but it can play an important role among other transportation options in Bay Area as soon as in ten years. Therefore, it deserves at least as much attention in your document as driverless cars and PRT systems.

I hope you find these comments useful. If you need more info on UAM systems, I'm happy to help.

Thank you,
Michael

Aurora’s eVTOL aircraft (pictured above) includes eight lift rotors for vertical takeoff and cruise propeller and wing to transition to high-speed forward cruise. Fully electric operation decreases or eliminates emissions and noise pollution for a quieter flight.

Airbus’s Project Vahana intends to open up urban airways by developing the first certified electric, self-piloted vertical take-off and landing (VTOL) passenger aircraft.

“I think flying cars will happen faster than any of us understand.”

- BOEING CEO DENNIS MUILENBURG

Uber is planning to commercially deploy air taxis by 2023.
The company has established a number of partnerships across an array of functions, most notably in vehicle manufacturing but also in air traffic control (NASA).
In terms of battery technology, Uber is developing its own long-lasting, fast-charging batteries for its electric sky taxis.

Lilium, the disruptive aviation startup developing a revolutionary on-demand air mobility service. The Lilium Jet is an all-electric VTOL personal aircraft that features rechargeable battery-powered ducted fan engines, retractable landing gear, fly-by-wire joystick controls, wing doors, panoramic windows, an interactive touchscreen and a large amount of storage.

The Lilium Jet can travel at up to 300km/hr and has a cruising range of 300km. The firm, founded by four engineers and doctoral students from the Technical University of Munich, claims that their two-seater (7m wingspan) prototype.

NASA defined a new research area called Urban Air Mobility (UAM) dedicated to managing air traffic and making it safe for vehicles to efficiently move passengers and cargo in a city.

https://cleantechnica.com/2019/09/07/urban-air-mobility-already-has-200-evtol-designs/