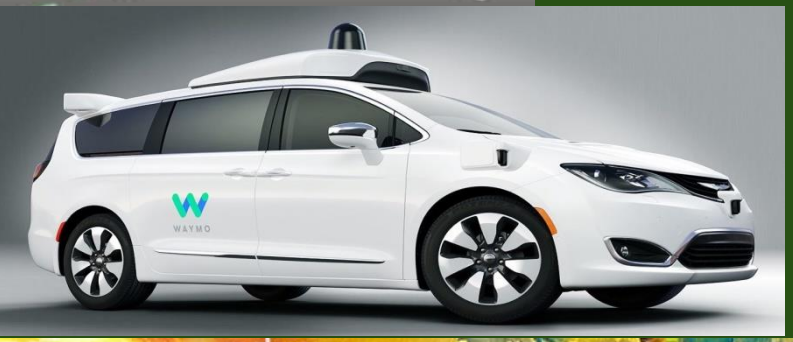

Planning for Autonomous Vehicles

Todd Litman

Victoria Transport Policy Institute

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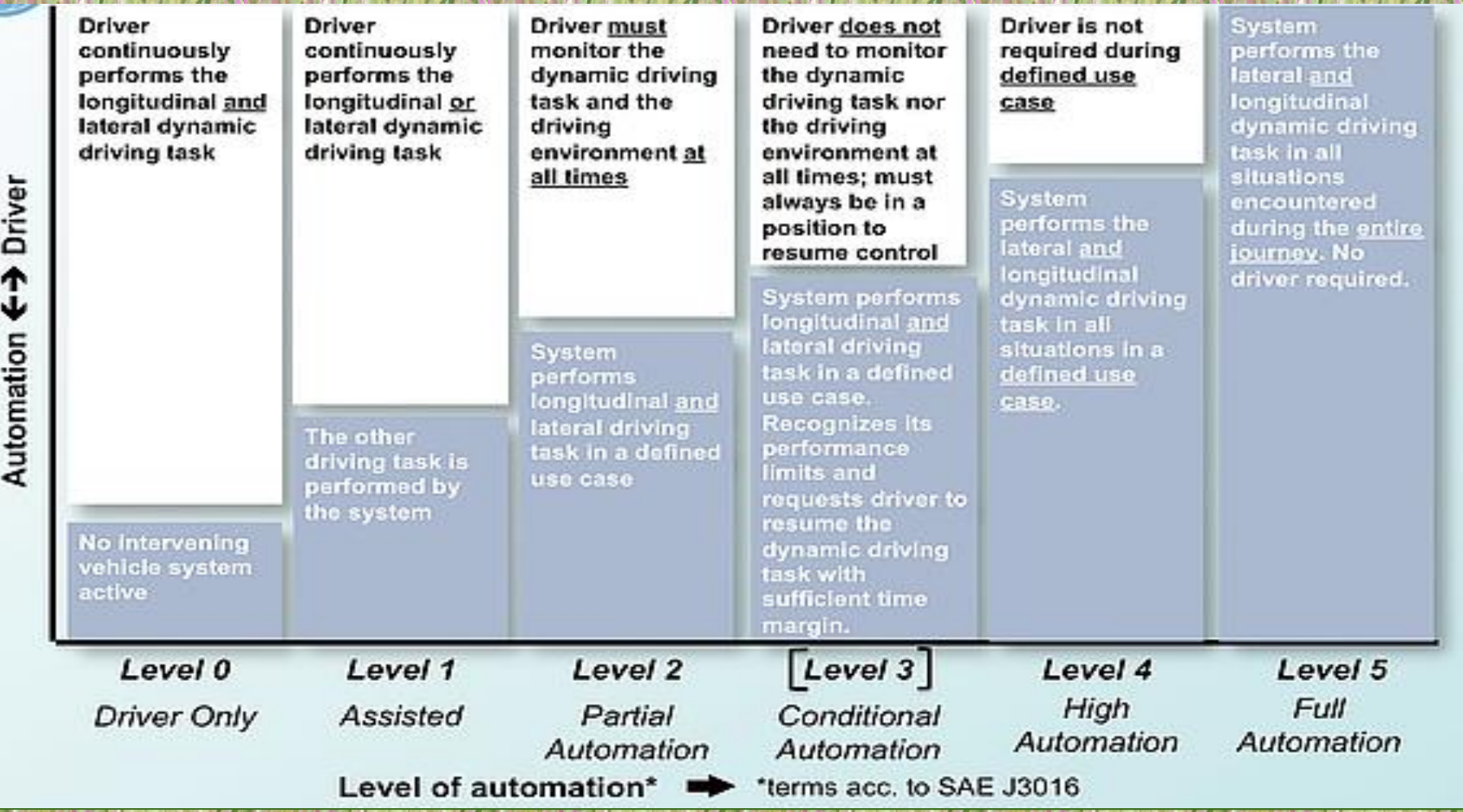
What About Autonomous Vehicles?

How will autonomous vehicles affect individuals and communities?

How should we change roadway design and management, parking and urban planning?

Automated Driving Levels



Operational Models

	Advantages	Disadvantages	Appropriate Users
Personal autonomous vehicles - Motorists own or lease their own self-driving vehicles	High convenience. Available without delay. Items, such as equipment, tools and snacks, can be left in vehicles.	High costs. Does not allow users to choose different vehicles for different trips, such as cars for commuting or trucks for errands.	People who travel a lot, reside in sprawled areas, want a particular vehicle, or leave items in their vehicles.
Shared autonomous vehicles - Self-driving taxis transport individuals and groups to destinations.	Users can choose vehicles that best meet their needs. Door to door service.	Users must wait for vehicles. Limited service (no driver to help passengers and ensure safety). Vehicles may be dirty.	Lower-annual-mileage users.
Shared autonomous rides - Self-driving vans (micro-transit) take passengers to or near destinations.	Lowest costs.	Least convenience, comfort and speed, particularly in sprawled areas.	Lower-income urban residents.

Direct User Benefits

- Less stress
- More productivity
- Independent mobility for non-drivers

Safety Impacts

Advocates predict that, because human error contributes to 90% of all traffic crashes, autonomous vehicles will reduce crashes by 90%.

This overlooks additional risks these technologies introduce.

Hardware and software failures. Complex electronic systems can fail. Self-driving vehicles will certainly have errors that contribute to crashes; the question is how frequently compared with human drivers.

Malicious hacking. Self-driving technologies can be manipulated for amusement or crime.

Increased risk-taking. When travellers feel safer they tend to take additional risks, called *offsetting behavior* or *risk compensation*. For example, reduced seatbelt use and more risk-taking by other road users.

Platooning risks. Many potential benefits, such as reduced congestion and pollution emissions, require *platooning*. This can introduce new risks.

Increased total vehicle travel. By improving convenience and comfort autonomous driving can increase total vehicle travel and therefore crashes.

Traffic Congestion Impacts

Unless roads are managed and priced for efficiency, autonomous driving is likely to increase traffic congestion:

- Increases total vehicle travel.
- It is often cheaper to drive on public roads than pay for an urban parking space.
- Reduced public transit services.

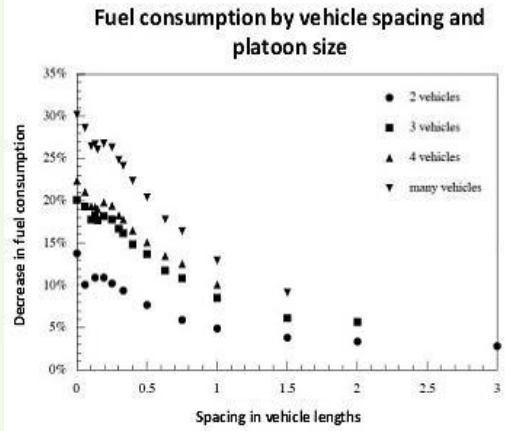
Bus

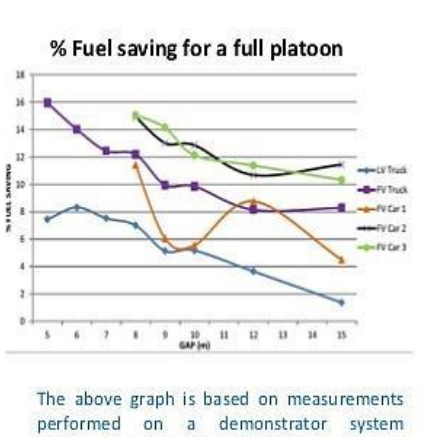
Human-Driven Cars

Self-Driving Cars

Benefit Requirements

- Some benefits such as reduced driver stress and increased productivity can occur under level 2 or 3 implementation, but many benefits, such as significant crash reductions, road and parking cost savings and mobility for non-drivers, require level 4-5 vehicles to become reliable and affordable.
- Reduced traffic congestion, energy consumption and pollution emissions require platooning, with vehicles travelling a few meters apart at relatively high speeds.





The above graph is based on measurements performed on a demonstrator system consisting of five vehicles: a lead truck (LV), a following truck (FV), and three following cars.

Owned Versus Shared Vehicles

Many projected benefits depend on vehicle sharing. But motorists have reasons to prefer owning rather than sharing their vehicles:

- *Convenience*. Motorists often keep items in their vehicles, such as car seats, tools, and emergency supplies.
- *Speed and Reliability*. Under optimal conditions, taxis arrive in just a few minutes, but sometimes much longer, especially in suburban and rural areas.
- *Costs.* Vehicle sharing is generally cost effective for motorists who drive less than about 6,000 annual miles. Suburban and rural residents, or other higher annual mileage drivers will probably choose vehicle ownership.
- *Status.* Many people take pride in their vehicles and their driving ability, and so may prefer to own and drive a personal vehicle.

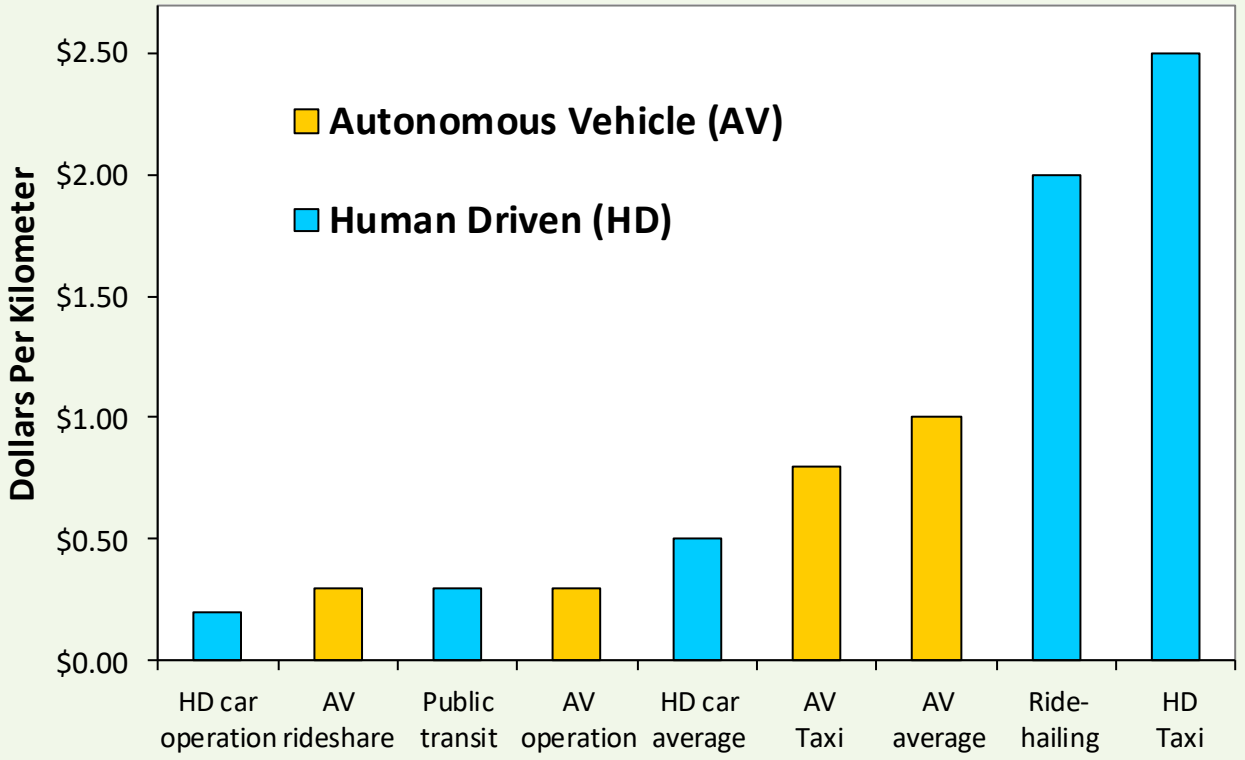
Equipment Costs

- Requires high-quality and redundant sensors, computers, controls, plus subscriptions to high-quality maps and specialized maintenance.
- This will add several thousand dollars to vehicle purchase prices, plus a hundreds of dollars in annual maintenance and service costs, probably increasing annual costs by $1,000 to $3,000.
- These incremental costs may be partly offset by fuel and insurance savings.

Typical Operating Costs

Some advocates predict that autonomous taxis use will cost less than 20¢/km, but this ignores cleaning, maintenance, empty vehicle-kilometers, and roadway costs, and profits.

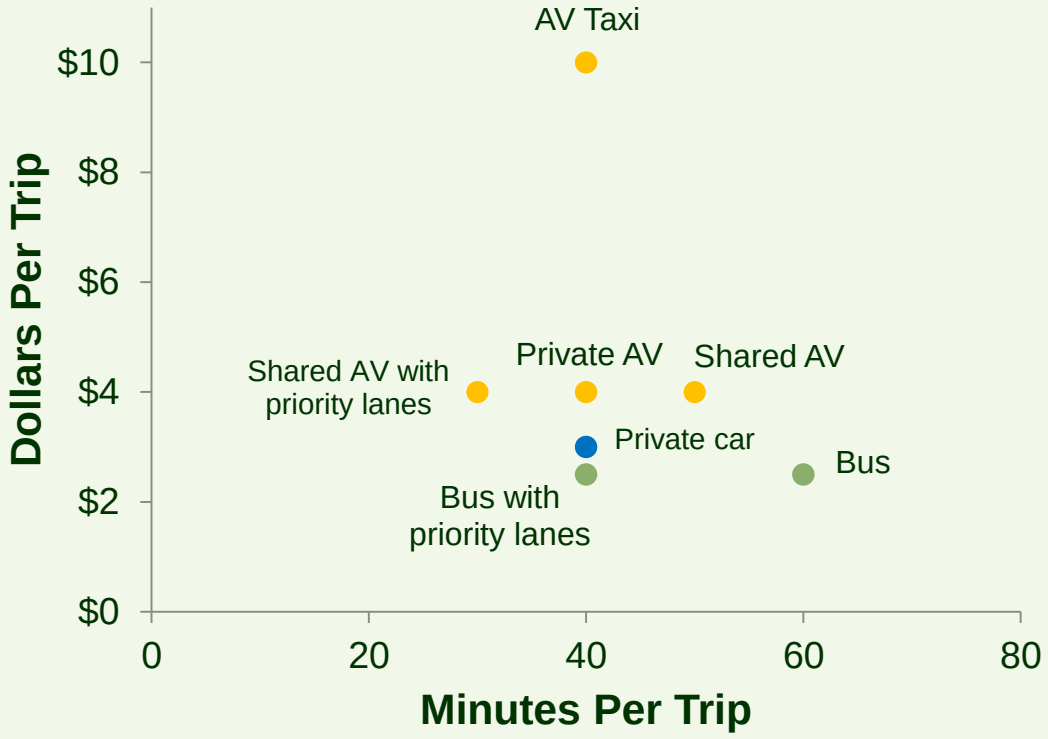
Autonomous vehicle travel will probably cost somewhat less than current human-operated taxis or ride-hailing services (Uber and Lyft), but more than current automobile travel.



Costs vary depending on vehicle type and ownership model. Although private vehicles (human driven or autonomous) are expensive to own, their operating costs are low, typically 20-30¢ per kilometer.

Typical 15-Km Commute

- $30 for a 40-minute human-driven ride-hailing trip.
- $3,000 in fixed costs and $3.00 in operating costs for a 40-minute human-driven trip.
- $5,000 in fixed costs and $4.00 per kilometer for a 40-minute private autonomous vehicle.
- $10.00 for a 40-minute private autonomous taxi trip.
- $4.00 for 50-minute shared autonomous taxi trip (30 minutes with priority lanes).
- $2.50 for a 60-minute bus trip (40-minutes with priority lanes).



Time and money costs vary.

Travel Impacts

Increases Vehicle Travel	Reduces Vehicle Travel
• Provides vehicle travel to non-drivers (people who are disabled, young or impaired). • Increased convenience and productivity increases travel. • Empty vehicle travel when dropping off or picking up passengers • Encourage sprawled development. • Reduces traffic congestion and vehicle operating costs, which induces additional vehicle travel.	• More convenient shared vehicle services allow households to reduce vehicle ownership and use. • Increases vehicle ownership and operating costs, further reducing private vehicle ownership. • Self-driving buses can improve transit services. • Reduced traffic risk and parking facilities can make urban living more attractive. • Reduce some vehicle travel, such as cruising for parking.

Autonomous driving can increase vehicle travel in some ways and reduce it in others. Total impacts will depend on the public policies implemented in a jurisdiction. This will affect external costs including congestion, roadway subsidies, accident risk and pollution emissions.

Potential Design Conflicts

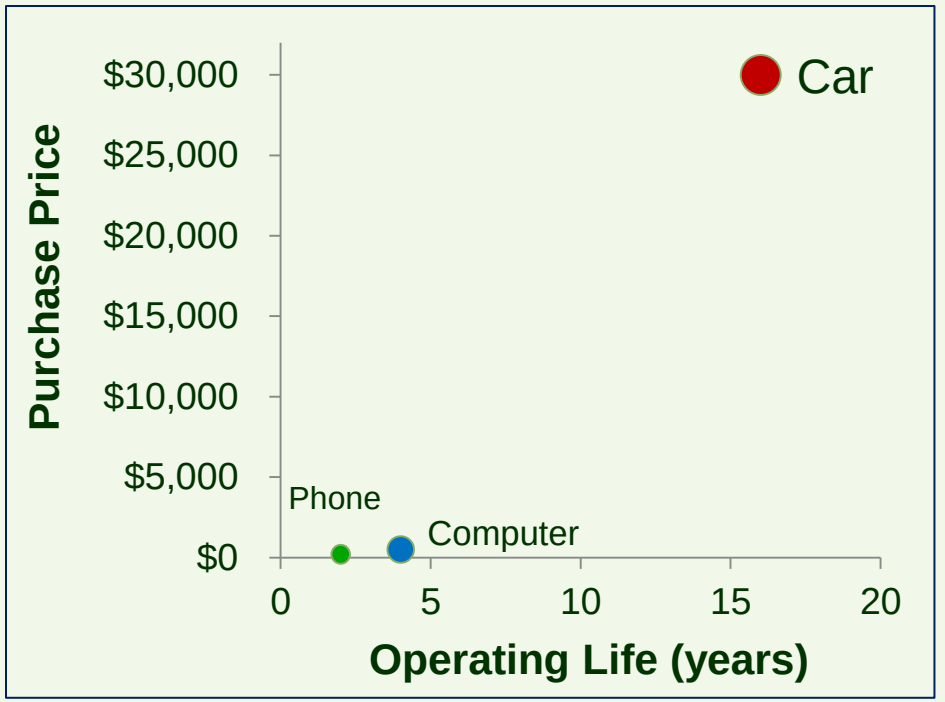
- If programmed to maximize sleeping passengers' comfort they may reduce traffic speeds.
- If programmed to protect occupants they may increase risks to other road users.
- Some benefits (reduced congestion and pollution) require dedicated autonomous vehicle lanes, which is unfair and requires regulation and enforcement.
- By increasing vehicle travel and traffic speeds, and displacing public transit, autonomous vehicles could exacerbate traffic congestion, sprawl costs, and mobility inequity.
- If parking is priced but roads are not, it is cheaper for vehicles to driving continuously on urban streets rather than pay for parking, increasing congestion and pollution.

Benefits	Costs/Problems
Reduced driver stress. Reduce the stress of driving and allow motorists to rest and work while traveling. *Reduced driver costs.* Reduce costs of paid drivers for taxis and commercial transport. *Mobility for non-drivers.* Provide independent mobility for non-drivers, and therefore reduce the need for motorists to chauffeur non-drivers, and to subsidize public transit. *Increased safety.* May reduce many common accident risks and therefore crash costs and insurance premiums. May reduce high-risk driving, such as when impaired. *Increased road capacity, reduced costs.* May allow platooning (vehicle groups traveling close together), narrower lanes, and reduced intersection stops, reducing congestion and roadway costs. *More efficient parking, reduced costs.* Can drop off passengers and find a parking space, increasing motorist convenience and reducing total parking costs. *Increase fuel efficiency and reduce pollution.* May increase fuel efficiency and reduce pollution emissions. *Supports shared vehicles.* Could facilitate carsharing (vehicle rental services that substitute for personal vehicle ownership), which can provide various savings.	*Increases costs.* Requires additional vehicle equipment, services and maintenance, and possibly additional roadway infrastructure. *Additional risks.* May introduce new risks, such as system failures, be less safe under certain conditions, and encourage road users to take additional risks (offsetting behavior). *Security and Privacy concerns.* May be vulnerable to information abuse (hacking), and features such as GPS tracking and data sharing may raise privacy concerns. *Induced vehicle travel and increased external costs.* By increasing travel convenience autonomous vehicles may induce additional vehicle travel, increasing external costs of parking, crashes and pollution. *Social equity concerns.* May have unfair impacts, for example, if they lead to reduced convenience and safety of other modes. *Reduced employment and business activity.* Jobs for drivers should decline, and there may be less demand for vehicle repairs due to reduced crash rates. *Misplaced planning emphasis.* Focusing on technological solutions may discourage communities from implementing conventional but cost-effective transport projects such as pedestrian and transit improvements, and demand management strategies.

Comparing Disruptive Technologies

Compared with other technologies, such as mobile phones and personal computers, motor vehicles:

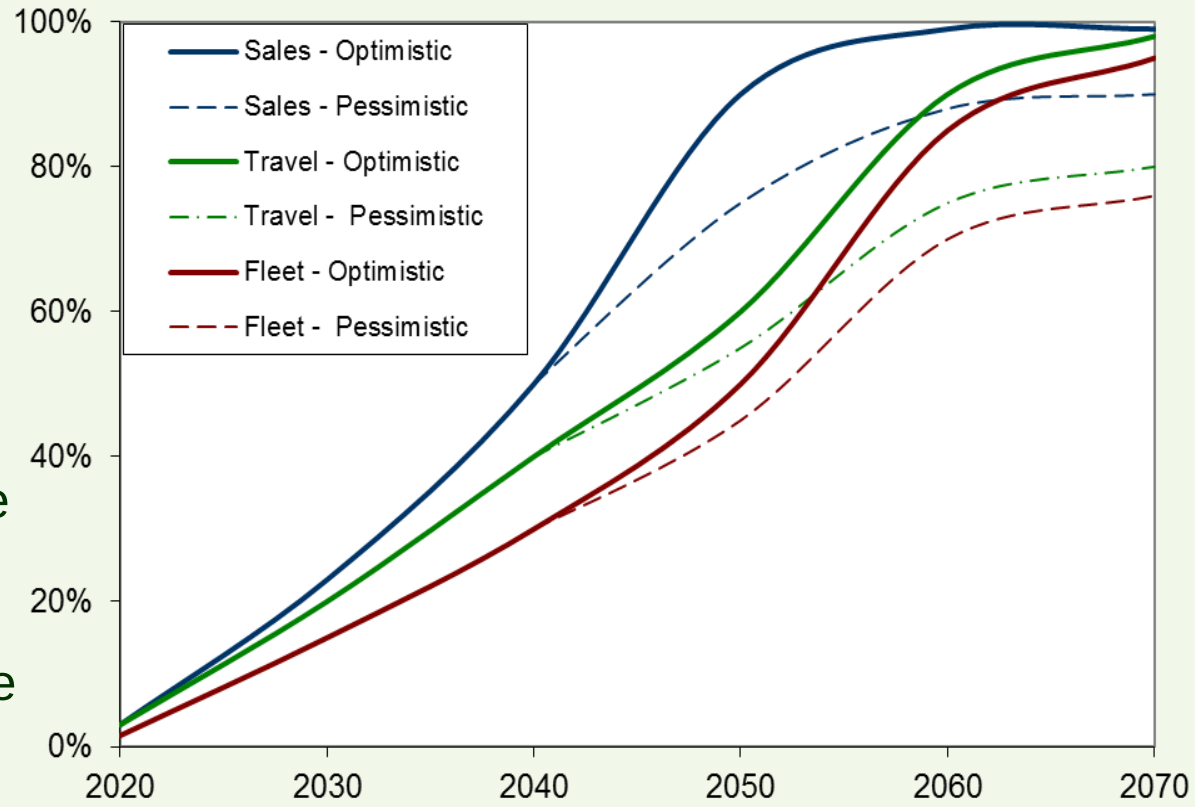
- Cost two orders of magnitude more.
- Last an order of magnitude longer.
- Have much greater safety risks.
- Impose larger external impacts (congestion, public roadway costs, accident risk and pollution emissions).



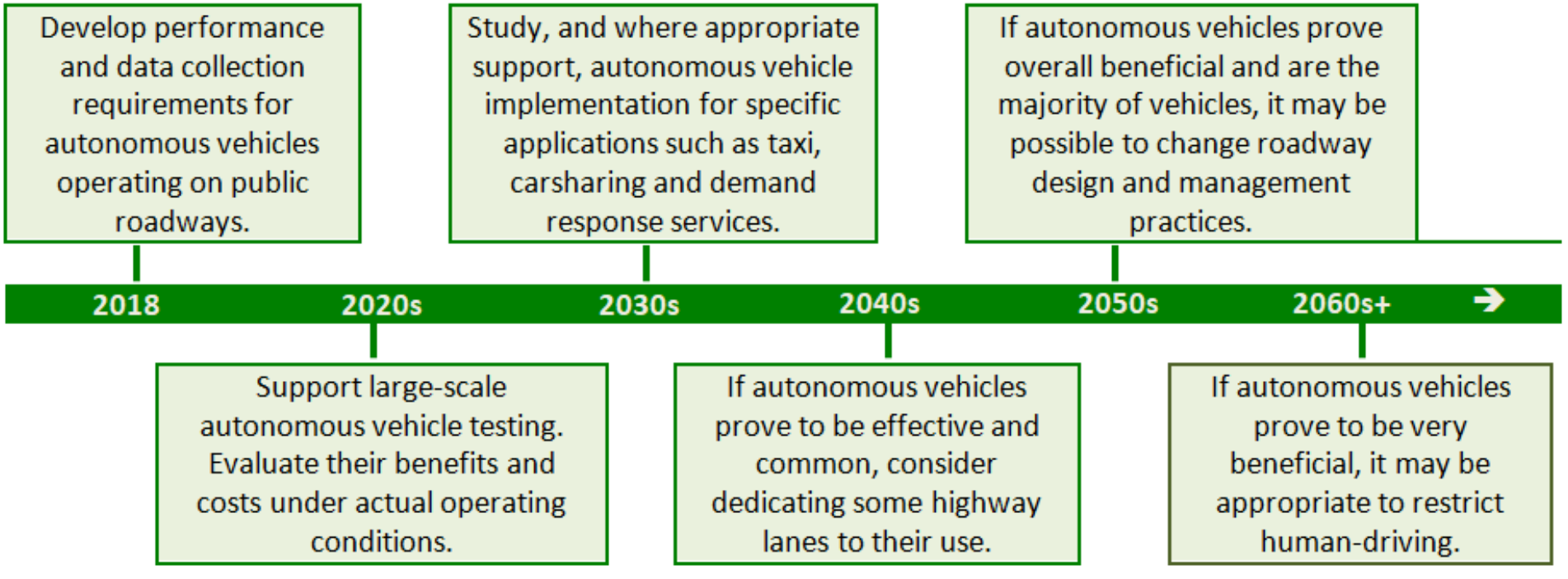
A typical car costs $30,000 and operates for 16 years, compared with $500 and 4 years for a personal computer, and $200 and 2 years for a mobile telephone.

Implementation Projections

If autonomous vehicle implementation follows previous vehicle technology patterns it will take one to three decades to dominate vehicle sales, plus one or two more decades to dominate vehicle travel, and even at market saturation it is possible that a significant portion of vehicle traffic will continue to be self-driven, indicated by the dashed lines.



Planning Requirements



Heaven and Hell (Robin Chase)

Heaven	Hell
• More vehicles are shared so total vehicle ownership declines. • Self-driving cars help create a more diverse and efficient transport system. • Walking, cycling and public transit conditions improve. • Less total vehicle travel. • Total transport costs decline.	• Most autonomous vehicles are privately-owned. • Support for walking, cycling and public transit services decline. Transport systems become more auto-dependent. • Total vehicle travel increases. • Traffic problems (congestion, accidents, pollution, user costs) increase.

Heaven requires policies that create more diverse and efficient transport systems:

- More efficient road and parking pricing.
- Increased walking, cycling and public transit investments.
- Reduced parking requirements in zoning codes.

Policies for Optimization

- Test and regulate new technologies for safety and efficiency.
- Require autonomous vehicles to be programed based on ethical and community goals.
- Efficiently regulate and price roads and curb space to prevent congestion.
- Favor shared and higher-occupant vehicles over lower-occupant vehicles on public roads.
- Support high capacity public transit on major travel corridors.
- Reduce parking requirements to take advantage of shared vehicles.
- Efficiently price development to prevent inefficient sprawl.

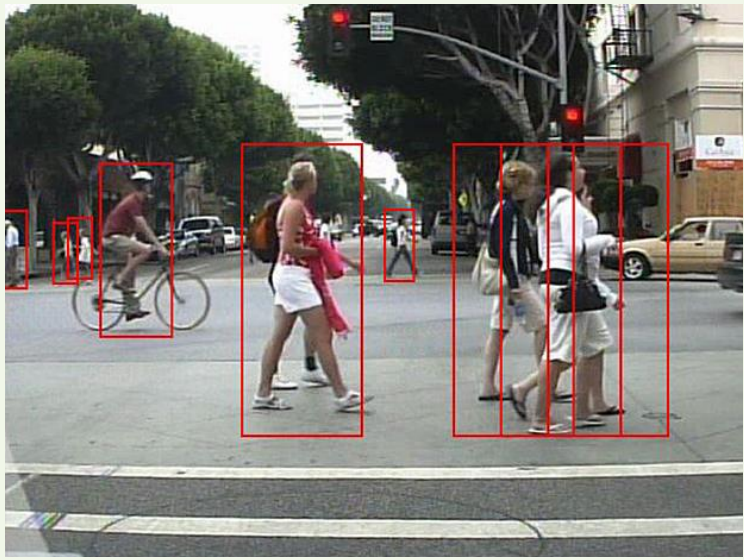
Principles for Livable Cities

1. Plan our cities and their mobility together.
2. Prioritize people over vehicles.
3. Support shared and efficient use of vehicles, lanes, curbs, and land.
4. Engage with stakeholders.
5. Promote equity.
6. Lead the transition towards a zero-emission future and renewable energy.
7. Support fair user fees across all modes.
8. Aim for public benefits via open data.
9. Work towards integration and seamless connectivity.
10. In urban areas autonomous vehicles should only operate in shared fleets.

(www.sharedmobilityprinciples.org).

Conclusions – Benefits and Costs

- There is considerable uncertainty concerning autonomous vehicle benefits, costs and travel impacts.
- Recent predictions that autonomous vehicles will soon be cheap and ubiquitous, and by 2030 will displace most private vehicle travel are mostly by people with financial interests in the industry based on experiences with disruptive telecommunications technologies
- Advocates often exaggerate net benefits by ignoring new costs and risks, *rebound effects*, and harms to people who do not to use the technology.



Benefits Will Vary

Net benefits will depend on whether public policies encourage vehicle sharing, and efficiently price road and curb space.

- **Urban** – Shared self-driving taxis can reduce vehicle ownership, saving users money.
- **Suburban and rural** – Personal self-driving cars will provide user convenience but increase total vehicle costs.

Conclusions – Deployment

- Vehicle innovations tend to be implemented more slowly than for other technological change due to high costs, strict safety requirements, and slow fleet turnover.
- Automobiles typically cost fifty times as much and last ten times as long as personal computers and mobile phones, so consumers seldom purchase new vehicles simply to obtain a new technology.
- Autonomous vehicles will initially be costly and imperfect.

Conclusions - Development

- During the 2020s and perhaps the 2030s, they are likely to be expensive novelties with limited abilities. It will probably be the 2040s before most middle-income families can purchase autonomous vehicles that can safely chauffeur non-drivers, and longer before they are affordable to lower-income households.
- Some people will probably prefer human-operated vehicles.
- It is unlikely that most vehicles to be autonomous before 2050 unless large numbers of functional vehicles are scrapped to accelerate deployment.

Conclusions – Planning Issues

- **Congestion and pollution.** If they stimulate more vehicle travel, self-driving vehicles can increase congestion and pollution, except where they have dedicated lanes.
- **Parking.** Shifts from owned to shared vehicles can reduce parking demands, and vehicles can park further away from destinations.
- **Crashes.** They reduce some risks but increase others. Net safety benefits will depend on policies.
- **Mobility for non-drivers.** They can improve mobility for affluent non-drivers, but non-drivers may be worst off if they increase urban traffic or cause public transit disinvestment.
- **Road and curb rights.** Cities should manage road space and curb rights for efficiency and fairness.

“Mobility and Innovation: The New Transportation Paradigm”

“Autonomous Vehicle Implementation Projections”

“Transportation Cost and Benefit Analysis”

“New Transportation Planning Paradigm”

“The Future Isn’t What It Used To Be”

“A New Traffic Safety Paradigm”

“Online TDM Encyclopedia”

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