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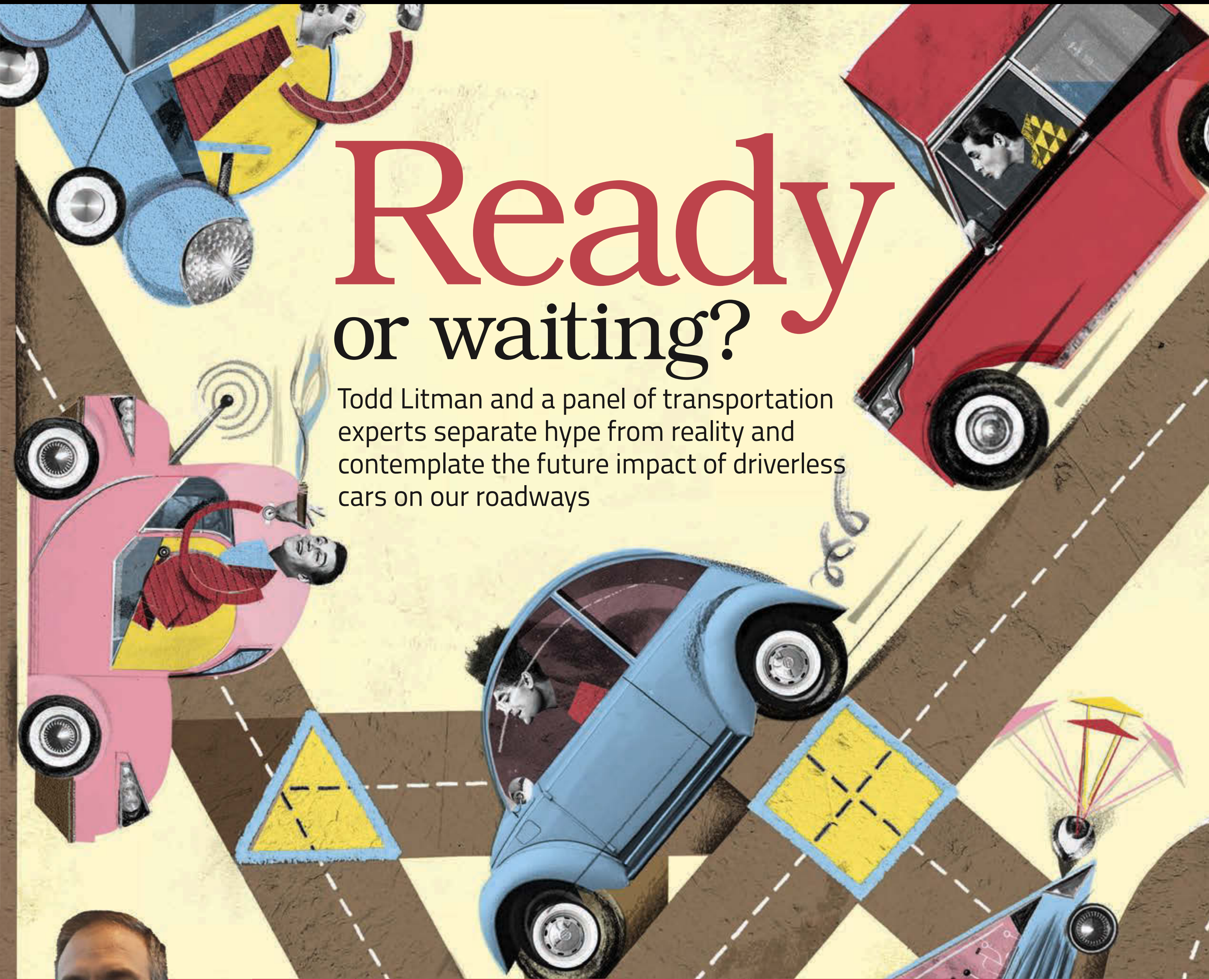

Ready or waiting?

Todd Litman and a panel of transportation experts separate hype from reality and contemplate the future impact of driverless cars on our roadways

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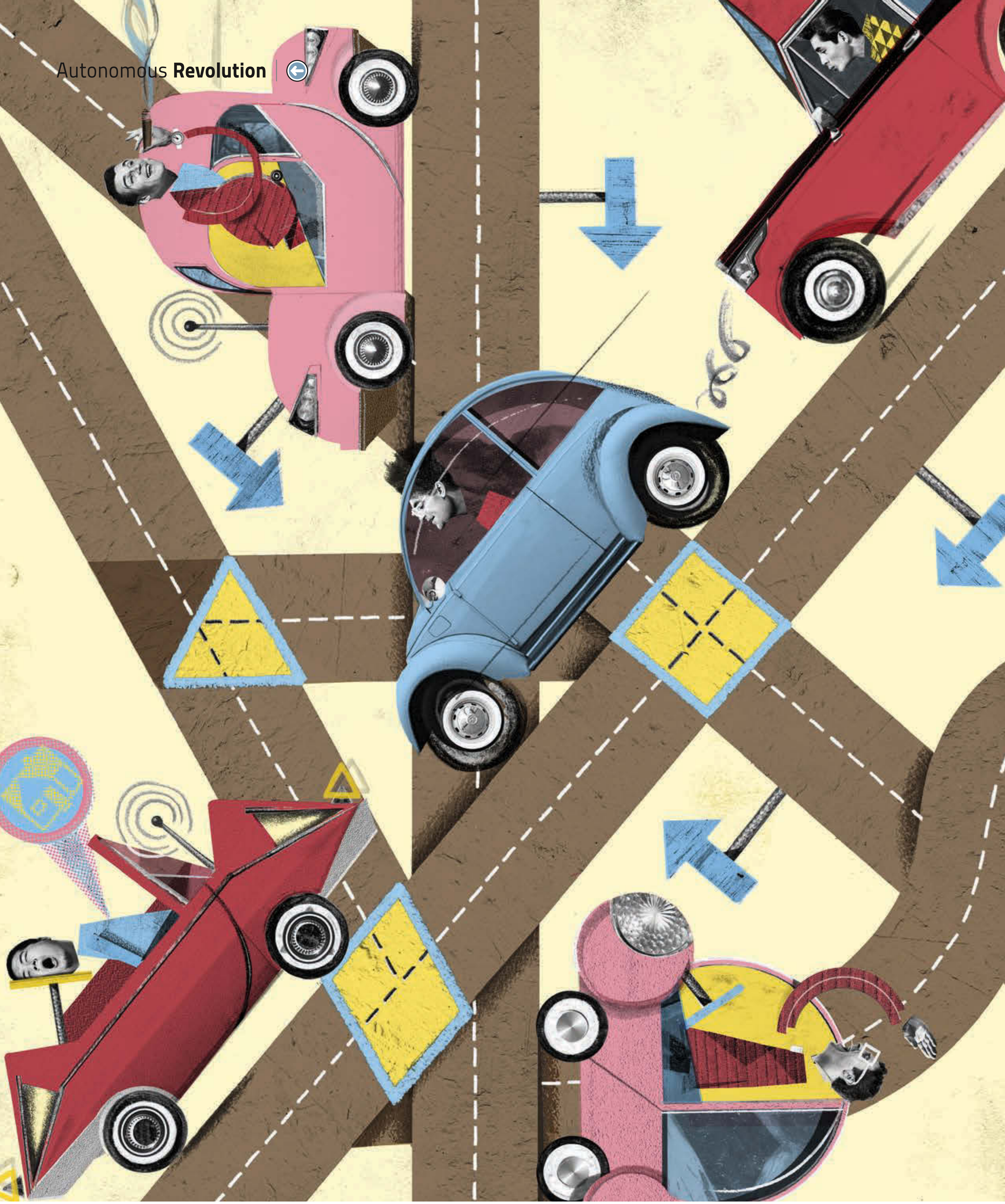


Ready or waiting?

Autonomous, self-driving vehicles are likely to develop and be deployed during the next few decades. But, asks **Todd Litman**, how will they affect transport planning decisions such as road and parking supply, as well as public transit demand?

Illustration courtesy of Arthur Chiverton

Motor vehicle technologies including communications and control systems have – and are – rapidly advancing. Many vehicles now come equipped with GPS navigation and collision avoidance systems. Automatic parallel parking and lane-assist capability, the latter keeping the car in the center of the lane, are beginning to penetrate more widely. As a result of these semi-autonomous functions, some experts predict that fully autonomous (aka self-driving, driverless or robotic) vehicles – which eliminate the need for a driver altogether – will soon become commonplace.[1] Advocates predict these will quickly revolutionize our transportation systems, making them safer, more efficient and easier to use.[2]

But it's premature to fire your chauffeur just yet. Even the most optimistic projections indicate it will be many years before a typical household can purchase a fully autonomous (level four) vehicle, and decades before they are common enough to substantially affect the need for roads, parking facilities or public transit services.[3] And even when they do reach market

Levels of autonomous vehicles[4]

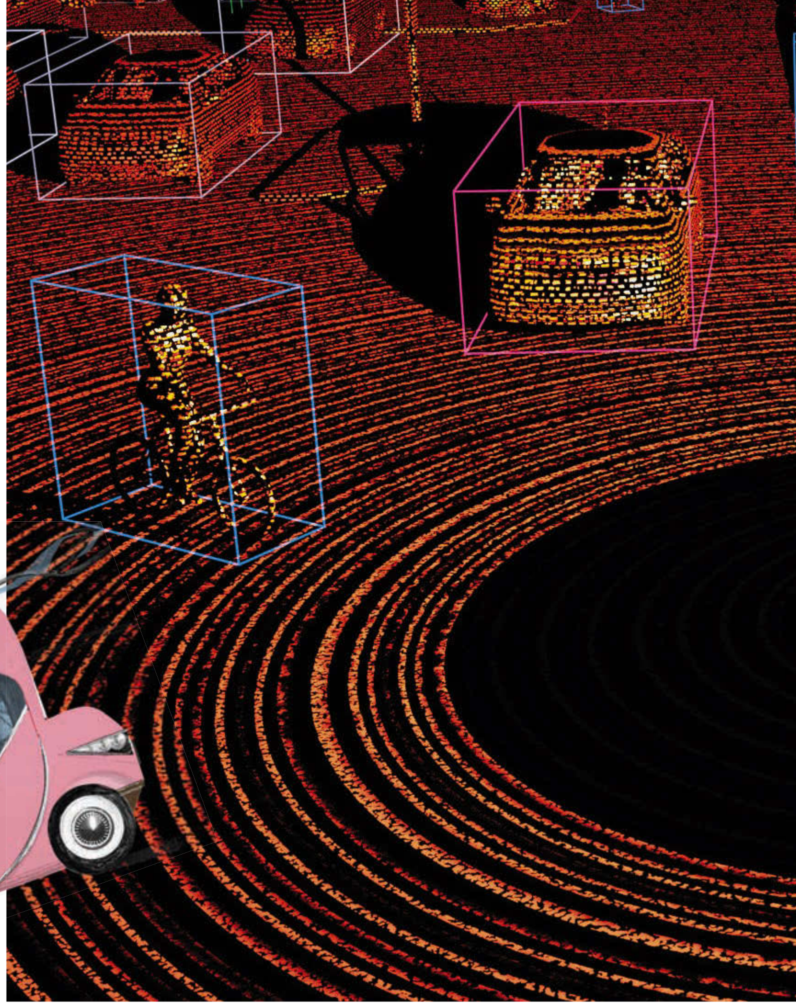
Level 1 – Function-Specific Automation: Automation of specific control functions, such as cruise control, lane guidance and automated parallel parking. Drivers are fully engaged and responsible for overall vehicle control.

Level 2 – Combined Function Automation: Automation of multiple and integrated control functions, such as ACC with lane centering. Drivers are responsible for monitoring the roadway and expected to be available for control at all times, but under certain conditions can be disengaged from vehicle operation.

Level 3 – Limited Self-Driving Automation: Drivers can cede all safety-critical functions under certain conditions and rely on the vehicle to monitor for changes in those conditions that will require transition back to driver control. Drivers are not expected to constantly monitor the roadway.

Level 4 – Full Self-Driving Automation: Vehicles can perform all driving functions and monitor roadway conditions for an entire trip, and so may operate with occupants who cannot drive and without human occupants.

Image courtesy of Volvo Cars



(Left) **Volvo's self-parking technology enables drivers to drop the vehicle off at the entrance to a parking lot, then use a cell phone app to activate the car's self-parking system, allowing the driver to just walk away** (Right) **How Google's self-driving Prius sees the world around it**

saturation, it's entirely feasible that many motorists will prefer to continue driving their own cars unless the use of autonomous technologies becomes mandated.

Benefits and costs

So what are the potential benefits and costs of autonomous vehicles? Is it possible to look at previous vehicle technology development and deployment patterns for clues and – based on this information – predict any timelines for autonomous vehicle implementation? And how are these vehicles likely to affect transport planning in future decades? Let's take a look…

Potentially, autonomous vehicles could significantly reduce stress levels and offer us the capability to rest – or work – while traveling. Driverless cars could also provide independent mobility for non-drivers, increase road capacity and reduce traffic congestion. They could additionally reduce parking costs, accidents, offer energy conservation, emissions reductions as well as more scope for vehicle sharing.

Some of these impacts, such as reduced driver stress and increased urban roadway capacity, may occur under level 2 or 3 implementation, which provides limited self-driving capability, but most benefits such as significant reductions in congestion and accidents will only occur after level 4 autonomous vehicles are affordable and become a major portion of vehicle traffic.

The ultimate incremental costs of autonomous vehicles is uncertain. Other, simpler technologies add many hundreds of dollars to vehicle retail prices. Optional rearview cameras, GPS and telecommunications systems, and automatic transmissions, for example, each typically cost US$500 to US$2,000 extra, while navigation and security services have US$200 to US$350 annual subscription fees. Autonomous vehicles require these plus other equipment and services.

Subscriptions to special navigation and mapping services may be required for autonomous vehicle operation. This suggests that – even when their technology and markets are mature – self-driving capability will probably add US$5,000 to US$20,000 to vehicle prices, plus a few

Despite progress, significant technical improvement is needed to progress from restricted level 3 to unrestricted level 4 operation

Jack Opiola D'Artagnan Consulting

We have to separate hype from reality. Truly autonomous vehicles that drive themselves on both interstates and urban congested centers of our cities are a lifetime away. I know all the announcements are playing to the hype, but the programming and computing power to produce a fully autonomous vehicle that can master the complications of urban driving without human assist isn't going to happen in our lifetimes. Full stop!

Assisted driving and semi-autonomous operations of a car are already occurring to some degree. Cars can parallel park themselves, or platoon together with a lead vehicle driven by a human, or navigate in a highway environment with a human in there to take over if the autonomy is exceeded or in an unforeseen circumstance. In short, how far does the human have to be away from the controls? In autopilot,

"Truly autonomous vehicles that drive themselves on both interstates and urban congested centers of our cities are a lifetime away"

the aircraft's captain is still there to take over the controls if need be. I think a similar thing will happen with cars. But the idea that the car will totally drive itself through an urban environment – with pedestrians and other road activity such as buses and roadworks while the driver is turned away reading a newspaper – just isn't going to happen in our lifetimes.

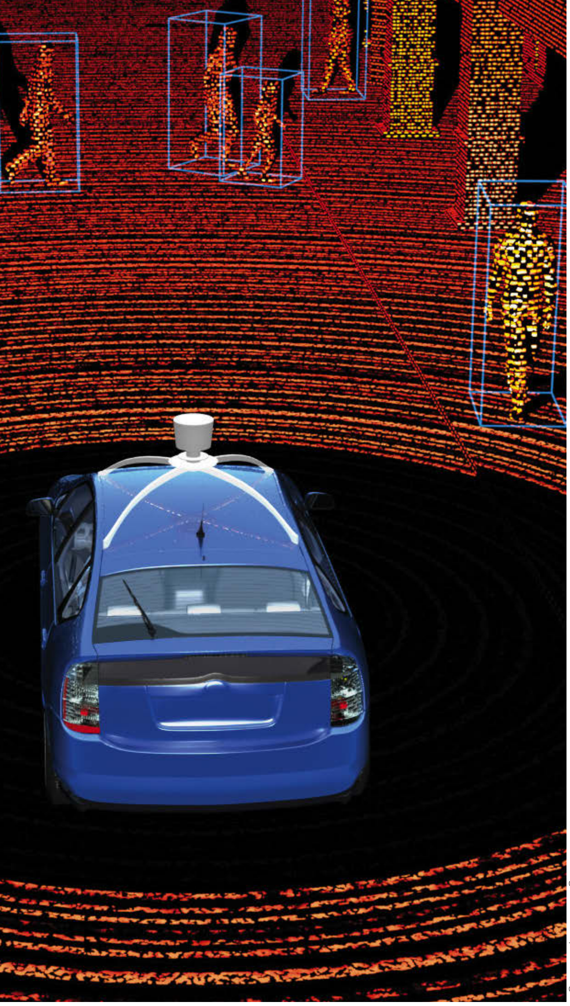


Image courtesy of Google

Paul Sorensen RAND Corporation

Despite impressive progress, there remains uncertainty surrounding the timeline for developing and deploying vehicle technologies with increasing degrees of automation. In addition to technical hurdles, there are also important issues related to regulation and liability to be resolved. The aggregate effects of automated vehicles on travel behavior are also unknown. For suburban or exurban dwellers, automated vehicle technology could allow drivers to sleep or work while traveling, reducing much of the disincentive for longer commutes and fostering sprawl and greater total vehicle travel. Within urban areas, in contrast, the technology could enable an affordable 'driverless taxi' service that results over time in denser development patterns with much lower auto ownership and less need for parking supply.

The prospects for automated vehicles, however, represent only one of many uncertainties that long-range transportation planners must contend with; others include the effects of improved telecommunications on travel, shifts in attitudes toward mobility among younger generations, and potential shifts in fuel sources and vehicle propulsion technologies. It simply isn't possible to point toward a particular envisioned future for which planners should be preparing. Instead, planners should adopt analysis methods that explicitly account for uncertainty and allow for the development of adaptive plans that should perform at least reasonably well however the future unfolds.

> "In addition to technical hurdles, there are also important issues related to regulation and liability that must be resolved"

hundred dollars in annual maintenance and service costs, increasing annualized costs by US$1,000 to US$3,000 per vehicle. These incremental costs may be partly offset by fuel and insurance savings. Motorists, for instance, spend on average approximately US$2,000 for fuel and US$1,000 for insurance. If autonomous vehicles reduce fuel consumption by 10% and insurance costs by 30% the total annual savings will average US$500, probably less than their incremental annual costs.

Currently, many new vehicles have some level 1 automation features such as automated cruise control, stability control, obstacle warning and parallel parking. Starting in 2014 or 2015, some OEMs plan to offer vehicles with level 2 features, such as autonomous lane guidance, accident avoidance and fatigue detection. Coordinated platooning is currently technically feasible but requires dedicated lanes, so isn't yet operational. Google level 3 test vehicles have reportedly driven hundreds of thousands of miles under restricted conditions: specially mapped routes, fair weather, and a human driver who can intervene when needed.[5] Some OEMs aspire to sell level 4 automation vehicles in a few years, although details are uncertain.

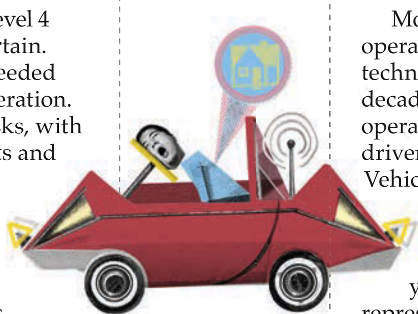
Despite progress, significant technical improvement is needed to progress from restricted level 3 to unrestricted level 4 operation. Such vehicles must anticipate all possible conditions and risks, with fail-safe responses. As a failure could be deadly to occupants and other road users, automated driving has high performance requirements. Sensors, computers and software must be robust, redundant and resistant to abuse. As such, several more years of development and testing could be required before regulators and potential users gain confidence that level 4 vehicles can operate as expected under all conditions.

Implementation projections

Autonomous vehicle implementation can be predicted based on the pattern of previous vehicle technologies and vehicle fleet turnover rates. Most new technologies initially have high costs and poor


Image courtesy of Bosch

Auto supplier Bosch believes continued improvement of autonomous systems over the coming years to make them work at faster speeds and in more complex driving situations will eventually lead to the availability of fully autonomous vehicles



performance, resulting in small market shares. They generally require two to five decades from commercial availability to market saturation, and without any government mandates coming into force will not be universal.

Modern vehicles are durable and can operate for decades. As a result, new vehicle technologies normally require about three decades to be implemented in 90% of operating vehicles.[7] Vehicles tend to be driven fewer annual miles as they age. Vehicles built in 2001, for example, averaged approximately 15,000 miles in their first year, 10,000 miles by year 10 and possibly only 5,000 miles by year 15, so vehicles older than 10 years represent about 50% of the vehicle fleet yet only about 20% of total mileage.[8]

For argument's sake, let's assume that fully autonomous vehicles will be available for sale and legal to drive on public roads around 2020. As with previous vehicle technologies, they are initially costly (tens of thousands of dollars price premiums) and imperfect (poor reliability and performance, and difficult to operate) hence represent a small portion of total vehicle sales. Market shares increase in subsequent decades as their prices decline, performance improves, and their benefits are demonstrated, so they grow as a portion of the total vehicle fleet. Over time they will increase as a share of total vehicle fleets. As newer vehicles are driven more than average annual miles, their share of vehicle travel is proportionately large.

With autonomous vehicle technology likely to add thousands of dollars to vehicle purchase prices, it may only provide large benefits to some users (high-income non-drivers, long-distance automobile commuters, and commercial drivers). It is therefore unclear what portion of motorists will consider the benefits worth the additional costs. It might, for instance, follow the pattern of automatic transmissions, which took nearly five decades to reach market saturation and still a portion of motorists continue to choose manual transmissions.

The implementation of driverless cars could be even slower and less complete than optimistic predictions. Technical challenges may be more difficult to solve than expected, so fully self-driving vehicles may not be commercially available until the 2030s or 2040s. They may have higher than expected production costs and retail prices, their benefits may be smaller or problems greater than predicted, while technical constraints, privacy concerns or personal preference may reduce consumer acceptance, resulting in a significant portion of vehicle travel remaining human-driven even after market saturation, indicated in Figure 1 by dashed lines.

Technical challenges may be more difficult to solve than expected, so fully self-driving vehicles may not be commercially available until the 2030s or 2040s

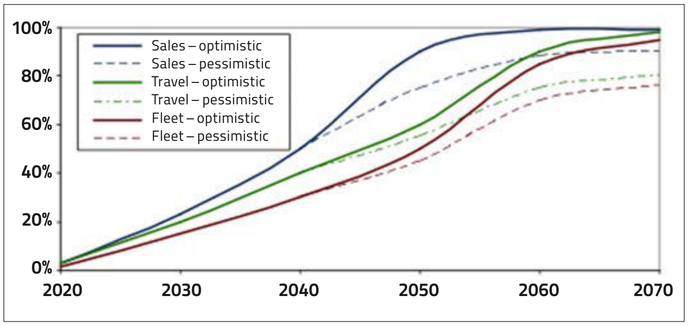


Image courtesy of Continental

(Figure 1, above) **Projected autonomous vehicle sales, fleet and travel. The dashed lines indicate pessimistic projections of saturation levels** (Left) **Germany's Continental says the first production-model self-driving cars will likely hit the roads around 2016**

Significantly faster implementation would require much faster development and deployment than previous vehicle technologies. For example, for the majority of vehicle travel to be autonomous by 2035, most new vehicles purchased after 2025 would need to be autonomous, and new vehicle purchase rates would need to triple, so the fleet turnover process that normally takes three decades can occur in one. This would require most low- and middle-income motorists who normally purchase cheaper basic or used vehicles to spend two to four times more to purchase a new autonomous vehicle, and many otherwise functional vehicles are scrapped just because they lack self-driving capability.

If autonomous vehicle implementation follows the patterns of previous vehicle technologies, it will take one to three decades to dominate vehicle sales, plus one or two more to dominate vehicle travel. And even at market saturation, it is possible a portion of vehicles and vehicle travel will still be self-driven. (Dashed lines indicate pessimistic projections of saturation levels.)

Figure 1 above illustrates projected deployment rates. If accurate, in the 2040s autonomous vehicles are likely to represent approximately 50% of new vehicle sales, 30% of the total vehicle fleet, and 40% of total vehicle travel. Only in the 2050s would most vehicles be capable of self-driving. The dashed lines indicate the possibility that, at saturation, a portion of motorists will choose to continue driving their own vehicles.

Bob Poole Reason Foundation

I am very skeptical of the Sunday supplement hype about AVs within a decade or two enabling a doubling of highway capacity, shifting vehicles from individually owned to an on-demand service, etc. Those might be very long-term possibilities, but until a great deal more work is done to resolve numerous liability issues, figure out how to make AV technology readily affordable for the mass market, and resolve AV safety issues enough to no longer require a human driver in place ready to take over in the event the automation fails or cannot cope with an emergency, it is very premature to be planning for a radically different highway system. One new report, from the Eno Foundation, even suggests reasons why large-scale use of AVs may increase VMT. I do think transportation planners should be more open to the idea of specialized lanes (urban freeway managed lanes, long-haul truck-only lanes on interstates), since some future AV transition strategies may restrict AVs to non-general-purpose lanes.

Transportation planning implications

So what of the functional requirements and planning implications of various autonomous vehicle impacts, and their expected time period? During the 2020s and 2030s, transport professionals will primarily be concerned with defining autonomous vehicle performance, testing and reporting requirements for operation on public roadways. If several years of testing demonstrate autonomous vehicle benefits, transport professionals may support policies that encourage or require self-driving capability in new vehicles.

When autonomous vehicles become a major share of total vehicle travel, they may significantly reduce traffic risk, traffic congestion, parking problems, and provide some energy savings and emission reductions. If these benefits are as large as proponents predict, transportation professionals will be involved in technical analyses and policy debates concerning whether public policies should encourage or require autonomous vehicles.

These impacts may vary geographically, with more rapid implementation in areas that are more affluent (residents can more quickly afford autonomous vehicles), more congested (potential benefits are greater) and have more public support.

Conclusions

Recent announcements that major manufacturers aspire to sell autonomous vehicles within a few years have raised expectations the technology will soon be widely available and solve transportation problems such as traffic congestion and accidents. But more critical analysis suggests that such vehicles will have only modest impacts during the foreseeable future.

There is considerable uncertainty concerning actual costs, benefits and deployment speed of autonomous vehicles. If they follow the patterns of previous technologies, early autonomous vehicles are highly likely to be costly and imperfect.

So in the 2020s and perhaps the 2030s, autonomous vehicles are likely to be expensive novelties that can operate under limited conditions, with a licensed driver at the wheel ready to intervene if and when required.

It will probably be the 2040s or 2050s before middle-income families can purchase vehicles that can safely chauffeur non-drivers, and longer before lower-income households can afford them. It is also entirely feasible that a significant portion of motorists will still prefer to drive their vehicles anyway, so the traffic make-up will be mixed, which in itself will create new roadway management problems.

A critical issue is the degree that these benefits can be achieved when only a portion of vehicles are autonomous. Some potential benefits, such as improved mobility for affluent non-drivers and more convenient taxi and car-sharing services, may occur when autonomous vehicles are relatively costly and uncommon. But most benefits require that most or all vehicles on a road are autonomous. It therefore seems unlikely that traffic densities can significantly increase, parking requirements be significantly reduced, traffic lanes be narrowed or traffic signals be eliminated until most traffic on the affected roads is automated.

• *Todd Litman is founder and executive director of the Victoria Transport Policy Institute, an independent research organization dedicated to developing innovative solutions to transport problems*

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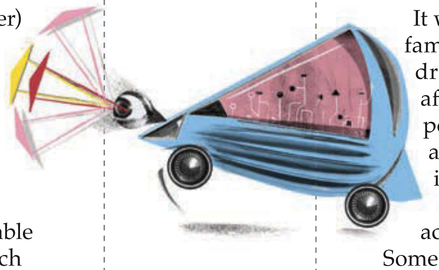
[6] *Litman (2013)*
[7] *ORNL (2012),* Transportation Energy Book, *Oak Ridge National Lab. (www-cta.ornl.gov/data), USDOE, Table 3.12*
[8] *ORNL (2012), Table 3.8*
[9] *Litman, 2013*

Peter Samuel *www.tollroadsnews.com*

Sizing roadways, bridge decks and tunnels rigidly for 3.6m or 12ft lanes and current mixes of vehicles looking to traffic forecasts of 2030 or 2040 is absurd. By 2020 we should be able to have – to cite just one example – many of our roads' vehicle systems steered so accurately they can run at higher speeds, with higher throughput, and in much narrower lanes – cars at least, maybe not trucks. Especially on major highways, we'll be looking to find ways to narrow specialized lanes for cars, and maybe provide for segregated roadways within the highway cars/trucks, autonomous/manual drive, etc. We need to be building our highways for flexibility and adaptation or repurposing as vehicle autonomy develops and spreads.

> More critical analysis suggests that such vehicles will have only modest impacts during the foreseeable future



Mobileye is aiming to get most of the functionality of autonomous driving into cars for much less, with fewer cameras and computer equipment costing hundreds – not thousands – of dollars

Image courtesy of Mobileye