CTRF 51 Annual Conference

CTRF-TRF Joint Conference

North American Transport Challenges in an Era of Change
Les défis des transports en Amérique du Nord à une aire de changement

Toronto, Ontario
May 1-4, 2016

Platinum Sponsor

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute
UTTRI

HOW CITIES CAN USE AUTONOMOUS VEHICLES TO INCREASE TRANSIT RIDERSHIP AND REDUCE HOUSEHOLD VEHICLE OWNERSHIP

Bern Grush, Grush Niles Associates, Toronto
John Niles, Grush Niles Associates, Seattle

Introduction

Automated vehicles and connected vehicles are highly anticipated. It is expected that over the next few decades innovations related to these two technology vectors will transform the automotive industry, personal mobility, public transportation, the taxi industry, land use, urban planning, transportation infrastructure, jobs, vehicle ownership, and many other physical and social aspects of our built world and our daily lives.

However certain we may be that fully autonomous vehicles (AVs) will dominate motorized urban and inter-urban transportation in the foreseeable future, everything else including its timing, cost, labour disruption, congestion, rights of way, and the management of interim fleets of mixed autonomous and non-autonomous vehicles can only be surmised. The constellation of unpredictable barriers and unforeseen innovations is far more extensive than the cornucopia of potential and hoped-for benefits.

We begin with a simple recap of the expected technology trajectory for robotic vehicles. Following that we consider the dimly-understood vehicle-capability landscape with which transportation planners must contend over the next 50 years. Next, we discuss vehicle ownership arguing that ownership will in the end be more important for sustainability and liveability than will the speed with which robotic technology matures and become pervasive. After this we present a case for robotic public transit and finally a process that uses robotic vehicles to dramatically expand transit ridership that we call *Transit Leap*.

Autonomous Technology Levels

Figure 1 shows the Society of Automotive Engineers' (SAE) standard for automated vehicle levels. It is against this that automotive manufacturers and suppliers can measure or assert their level of automation. These stages represent incremental improvements—a "feature creep" that standardizes comparable improvements, engenders interest, excitement, and consumerism, all of which fuels innovation. It will also encourage household ownership, low-density development, congestion, and non-active transportation.

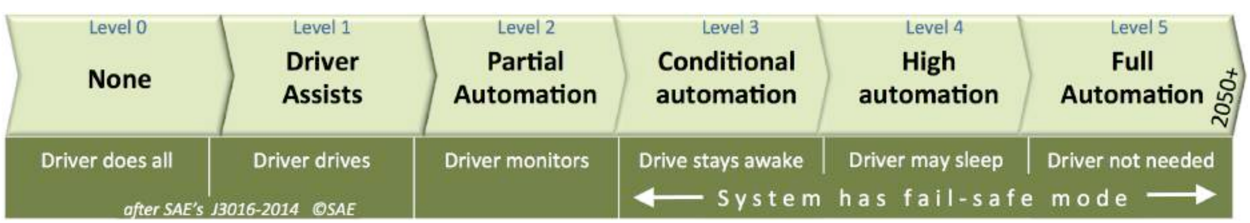

Figure 1: The SAE standard description for automated vehicle levels.

Incremental innovation, which is endemic to most consumer product development, adds autonomous vehicles one household at a time. As household vehicles with automated capabilities are adopted, for the first ten or 20 years, a majority will be level 3 or lower possibly creating a planning horizon of some complexity such as projected in Figure 2. We will require at least some penetration of level 5 vehicles before we see the start of significant changes such a dramatic reduction in parking needs, loss of driving jobs, or robotaxis arriving in two minutes after a smart app request.

The Next 50 Years

The common view regarding progress being made toward *full* (level 5) vehicle autonomy is exaggerated—at least by North American mass media and at automotive trade shows. Encouraged by what appear to be rapid advances in Advanced Driver Assistance Systems (levels 2 and 3) and fever-pitch hype from consultants,[1] Silicon Valley and now Detroit, Europe and Asia, many people get the impression that all this will unfold in the next few years. In some circumstances, this causes jubilation among car-sharing advocates and despair among transit authorities. But it is unlikely that level 5 vehicles will soon be given carte blanche in our cities. More tellingly, the technology consulting firm, Gartner, argues that we have just entered a period of disillusionment that will last for the next 5 to 10 years.[2]

Jurgen Nieuwenhuijsen from Technical University, Delft has compiled an informative set of *Everett Rogers* innovation graphs regarding market penetration for these vehicles extending out past 2075.[3] Figure 2 shows his modelled projection for a high economic growth scenario. Low economic growth scenarios drag out level 5 even longer. "Market penetration", here an amalgam of deployment readiness and vehicles sold, may bias this time projection optimistically.

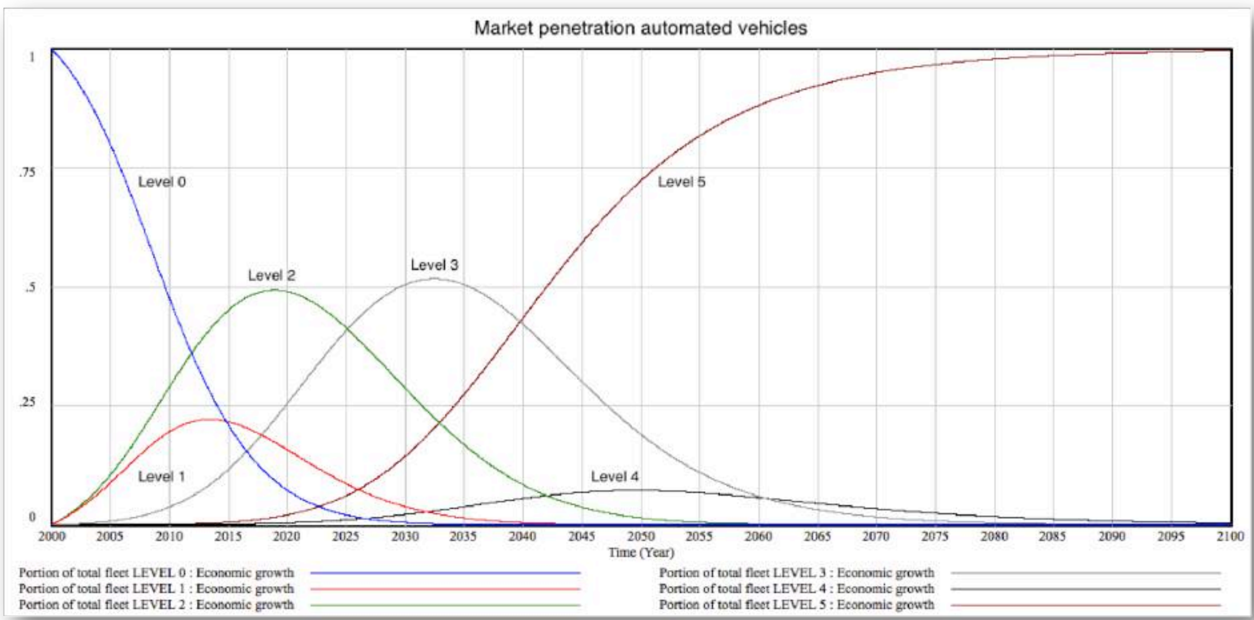

Figure 2: This plot illustrates the transportation planner's nightmare: a long, upcoming period of shifting vehicle capabilities. Early on, this will influence safety and infrastructure decisions (many temporary and not previously tried). As time proceeds, social issues such as land-use planning will shift and even later disruption to transit planning and jobs will begin. (Image credit: Jurgen Nieuwenhuijsen, TUDelft, 2015)

What is critical about this view is that prior to a high degree of level 5 penetration we might expect 35 or 40 years of mixed fleets of varying levels of semi-automation. Such a long period of time—analogous to the 40 years it took for the conversion from all horse-drawn vehicles to all motor vehicles—would have us contend with distracted driving, complex and shifting infrastructure planning and street re-organization (think about *Complete Streets*), temporary rights of way changes, churning land-use policy and very difficult questions about transit planning and changing meanings for transit oriented development. Regional and urban planners will experience the most daunting planning horizon they have ever faced.

Consider that while level 2 and 3 automation technology is progressing apace, vehicles so equipped will always require a responsible driver at the wheel. For unconstrained deployment of fully autonomous level 5 vehicles—the technology that gives us robocabs, no more parking, napping while "driving", driverless transit, and many other expected benefits—there are many hurdles. A level 5 AV has to handle an unknown number of difficult and low-probability events, its needs an unspecified level of infrastructure readiness, or at least consistent signage, lane-markings and other grooming, and it needs a body of regulations that has not yet been fully mapped out. To further underscore the uncertainty facing transportation planners, Nieuwenhuijsen provides another illustration (Figure 3), about which he writes: *"a majority of the experts expect the market to adopt level 5 automation in an s-shaped curve. The rapid adoption will happen between 2035 and 2060. This same majority expects level 5 to gain full market adoption. A minority of the experts expects that level 5 will not gain the full market share, as this market will be shared with either level 3 and/or level 4 vehicles."*[4]

Can proactive governments shape an intended future rather than simply "wait and see"?

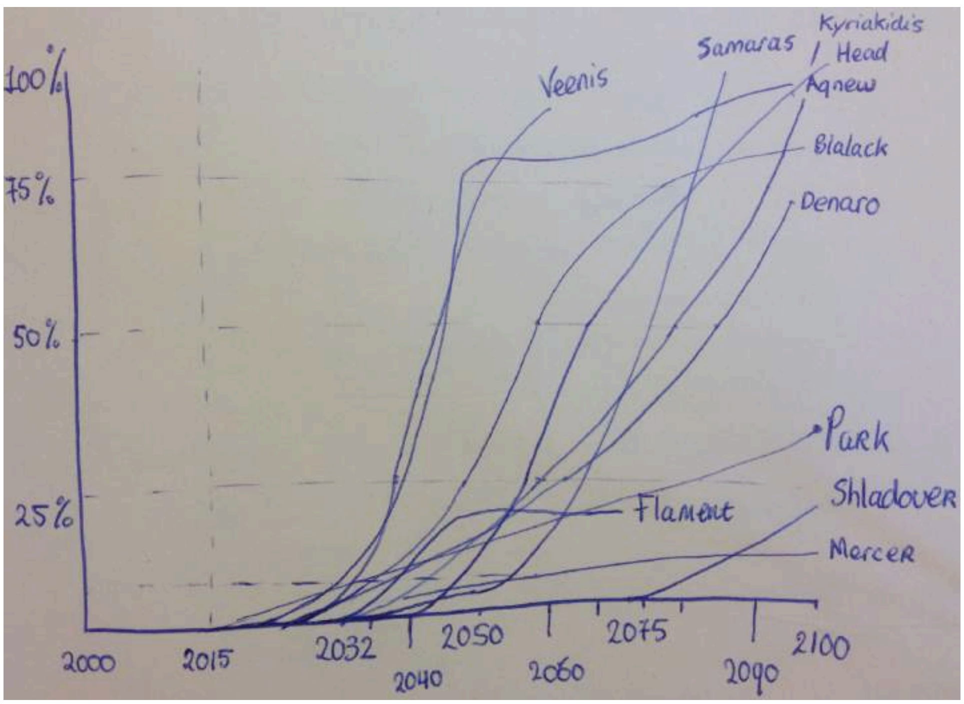

Figure 3: Eleven experts describe their expectations regarding market adoption of level 5 vehicles. (Image credit: Jurgen Nieuwenhuijsen, TUDelft, 2015)

Ownership will be Decisive

We assert that by the time the driver finally exits the majority of vehicles, vehicle ownership will be the pivotal issue for sustainability. More important than the then-current penetration level of robotic vehicles in, say, 2050 will be whether the majority of then-extant passenger vehicles are personally owned household vehicles or are deployed in massive publicly or privately operated robo fleets. It will matter more how we end up managing our motorized fleets, and less how long it took to get the driver out.

Much of the thinking about the future effects of robotic vehicles relies on the fact that they are expected to require no driver, no steering wheel, and even no human passenger. Some of this thinking assumes that the preference for ownership of a personal, household vehicle will decline, perhaps even plummet toward zero—becoming the social equivalent of owning a private jet. While some prognosticators are bullish about this outcome, others are not. Some even suggest there may be a rise in the population of household vehicles since independent vehicle use would now become feasible for many more individuals. More realistically, KPMG in a recent report suggested that household ownership might level off or decline slightly.[5] We also need to recognize that as we continue to urbanize, populations will continue to attract more household vehicles into our cities, albeit hopefully at a slower rate. In this case, normal growth in human populations could cancel or even overwhelm any modest decline in relative ownership rates.

Automated motor vehicles could be owned in any of several ways. Setting aside logistics and service vehicles, we postulate three primary ownership scenarios regarding the future of personal automobility and passenger transportation as we approach the era of self-driving vehicles.

Personal (Household) Ownership

The first of these scenarios is that by-and-large households will continue to own vehicles and that these owners will be considerably relieved of the tedium of driving, the danger of crashes, the cost of insurance and would be able to work, sleep, or socialize while traveling instead of fuming about congestion. Individuals, families or businesses will acquire these vehicles, just as household vehicles are purchased or leased today. The key attribute of these vehicles is that they would belong to one family or person: i.e., they would be a private household vehicle. The number of extant vehicles in concurrent operation would *increase with population growth and population wealth* as happens now. There is a risk of an even greater increase since people who cannot operate non-autonomous vehicles could use fully robotic vehicles.

Private (Corporate) Ownership

A second scenario—counter to the first—is that many or perhaps most people would no longer own a vehicle and instead would summon a vehicle that is perfectly suited to the immediate trip at hand. Such a vehicle would arrive of its own accord within a few minutes, take the traveler to his or her destination, and then move on to another passenger, visit a recharging station, or suspend in a waiting area. These vehicles would be owned by a commercial operator, which would charge rent. In aggregates of various sizes, these would form rental or carshare fleets similar to rental or carshare operations today. If these were provided robotically (no driver) they would behave as a hybrid of Car2Go and Uber. To dominate household ownership by VKT volume, they would have to be cheaper than either Car2Go or Uber are today. Two key attributes of these vehicles are that they would be *shared and operated as a sustainable business—i.e., for profit*. In the absence of transit, transportation equity would have to be regulated and possibly subsidized. These vehicles could be engaged for serial sharing (carsharing) or parallel sharing (ridesharing). This difference does not alter the ownership model; it only affects social expectations.

Public Ownership

A third scenario recognizes that the readiness of our transportation infrastructure to permit self-driving vehicles safe passage on every or even most roadways is much further off than might be level 5 vehicle automation—the vehicle technology might be ready within five years, as touted, but full road readiness is unlikely to be so. This means that self-driving vehicles would have at least some access restrictions limiting their utility both as a completely driverless, level 5, household vehicle or a robotaxi—i.e., regulations will demand that a driver remain in the vehicle, although largely idle—except on restricted routes and areas or at restricted speeds.

This public ownership scenario would involve the use of automated vehicles—such as the minibuses trialed in the EU by CityMobile2—moving initially at modest speeds along prepared routes or within constrained areas as a new form of public transit able to fully replace many fixed route city bus systems in perhaps a decade. This third scenario assumes that these vehicles would co-habit our streets with constrained-access robotaxis and household vehicles at varying levels of automation (levels 1 through 4).

These autonomous vehicles would be owned or at least controlled by public agencies in the form of transit vehicles operated under government operational direction—mostly municipal or regional. With public ownership, key attributes are *shared vehicles (serial or in parallel) and transportation equity*—i.e., mobility access for all income and ability levels.

Public-Private Partnerships

As a funding variant on public ownership, some autonomous fleets of transit vehicles might be managed within public-private partnerships (P3) so that physical vehicles would be owned and operated by a commercial operator, with pricing, routing, scheduling and fleet governance under government regulation. Perhaps the best balance, such fleets could have sustainability attributes to justify a private investment to conserve taxpayer money, while having personal accessibility attributes regulated to *ensure transportation equity*.

Among these three models, household, corporate and public, it is currently unpredictable how ownership will settle out after vehicle fleets become fully robotized. Some scenarios are based on desirable and rational projections that assume a majority of trips would be taken in highly optimized robocab fleets;[6,7] other scenarios are based on simulations that start from the current state and use minor perturbations to arrive at future states that look like mostly household ownership with a slight increase in sharing;[8] yet others have polled experts to average a larger group of knowledgeable opinions.[9]

The Urban and Social Logic of Ownership

These three ownership models compete. Simplistically, the ideal for automotive manufacturers would be to have each consumer own at least one motor vehicle, obviating every other form of ownership. While every automotive executive understands this is unsustainable, as a group they prefer that ideal and to date they have succeeded admirably. The downside of this for our cities does not need reiteration.

The ideal for private transportation companies (such as taxis, shuttle/bus operators and TNCs) would be to have all trips taken in one of their vehicles. The same competitive thinking applies and the CEO of Uber has been very much on record in this regard. If his future robo-Ubers were the only vehicle in the world, his shareholders would be pleased. While there is a celebrated upside to having all imagined passenger trips in a robocab, by what mechanism can transportation equity and access be assured regardless of ability to pay or ability to perambulate? The private-company robocab would, by default, be a for-profit company. We see already that TNCs, such as Uber, cherry-pick the easiest and most lucrative taxi-fares leaving the rest to a declining travel experience and eventually, one can surmise, to declining access.[10] In the extreme, making all or most trips in commercial robocabs socially workable would require considerable regulation, oversight and enforcement.

An ideal for public-transit minded planners would be to have an optimized, dense, and always-available transit network that is also affordable for the taxpayer. While we have not yet found a way to that Nirvana, it occurs to some that the autonomous vehicle provides an enabler to get much closer. While the driver-in vehicle of 2015 heavily biases ownership toward the personal household vehicle, the impending driver-out vehicle of the last three-quarters of this century may be able to change this imbalance.

The expected productivity and cost benefits of the impending technology, and the innovative, nimble, profit conscious players behind robotic automotive technology combined with the social media technologies that underpin TNCs suggests that transit ridership is at risk of being decimated. If this were to happen, the relative subsidy required for any residual ridership would likely mean the collapse of bus transit to be replaced by some combination of household and corporate robo fleets. Unfortunately, much of the market futurism one can read today argues that one or the other of household or corporate robo-fleets will dominate our urban future. Less often does this analysis explore whether today's bus-transit can—or should—survive. Even less ask *how* it might survive.

While the end of bus transit might sound good to some—especially those not using the bus—consider that of the alternatives, the household vehicle tends to maximize relative congestion and the corporate vehicle cherry-picks its customers. This means that a passenger-travel world divvied-up between household vehicles and commercial robo fleets risks becoming just an updated version of today—congested for the middle class and the rich, and diminished job accessibility for the poor. If municipalities simply "wait-and-see", the tendency for vehicle manufacturers and commercial robo-fleet operators to dominate the system architecture of personal motorized surface transportation will become unstoppable.

No single ownership model—household, corporate, or public—is perfect. And each has a valuable role. To have one model overwhelm the others, as is the current case, is known to be unsustainable, even if the future AVs were cleaner, safer and smarter. Ideally, a more equitable balance and even a tipping away from household ownership would be far more sustainable and appropriate to livability and active transportation. We authors propose, as an *intended future*, a shift in the ratios of household-corporate-public from the current, rough distribution of 90, 5, and 5 percent (respectively) to 20, 40, and 40 percent. This can only be achieved if transit authorities recognize their opportunity and set out to proactively grab the brass ring. The automakers and transportation network companies are already sharply focussed on maximizing their portion. In the absence of self-disrupted transit, the most likely outcome will be 70/30 in favour of one of either household or commercial fleet ownership. And it seems difficult to forecast which.

The Case for Autonomous Transit

Confounded with the future direction of vehicle ownership is the future of urban transit, especially bus transit. Personally owned autonomous vehicles, were they to become as safe, convenient and effective as promoted, and if the total cost of ownership were to become so affordable as generally happens after years of extensive innovation, this technology would dramatically erode current transit ridership. As well, if massive robotic, commercial fleets, optimized for effective service were to materialize at the touch of a smart phone, as promised, it is hard to see how today's bus transit could survive.

> "A recent study by the Boston Consulting Group found the cost of conveying one passenger by an autonomous vehicle would be 35% less than by conventional taxi at the average taxi occupancy rate of 1.2 passengers. Increase an autonomous vehicle's rate of occupancy to just two passengers and the cost per passenger becomes competitive with mass transit." [11]

Given the nature of the disruption promised by the level 5 autonomous vehicle and the promise of cheap on-demand robo-fleets, the transit of 20 or 30 years from today cannot resemble the transit of today. It cannot be dominated by large vehicles on fixed routes and rigid schedules—although there may be a residual role for some of that. It cannot be focussed only on commuters to and from work. It cannot be sustainable serving only a small fraction of total trips. While many criticisms of bus-transit may be addressable with replacement fleets of purpose-sized, robotic vehicles providing an extensive menu of flexible services and schedules, either transit ridership will have to grow substantially or be absorbed into the expected commercial robo fleets. Most government jurisdictions can ill-afford high per-trip-subsidies for modest ridership.

Either public transportation must evolve dramatically or it will not persist. How this unfolds matters for transportation equity. The case for autonomous transit is simple: adapt or die.

Transit Leap

While there is a chorus of promises from Google, Tesla, Volvo and now many others of the impending delivery of autonomous technology, there remain many barriers to deployment of level 5 autonomy. In spite of that, the social promise of greater safety is sufficient reason to achieve level 5 value sooner.

To access AVs advantages sooner, we propose a leadership role that municipalities and regions can play starting immediately. This would offer critical value for autonomous vehicle adoption. In addition to long run transportation equity, there are immediate opportunities available from engaging automotive innovation leaders for earlier realization of the advantages of autonomous vehicles and to circumvent, by spatial constraint and path grooming, many of the barriers to early level 5 deployment. As well, there are mid-range (second decade) opportunities for job preservation and to begin eroding revealed preferences for household vehicle ownership.

Transit Leap comprises an intentional, viral growth of automated people-mover applications (Figure 4). Beginning with constrained short, repetitive, fixed routes, moving through opportunistic stages of growth in route length, coverage area, schedule flexibility and app-based service levels, Transit Leap changes, over a span of two or three decades, from a small, slow, local service of a handful of vehicles into massive swarms of on-demand (and some scheduled) vehicles and routes. This approach adds clusters of autonomous vehicles one constrained area at a time, growing market adoption (and its social value) spatially rather than consumer-by-consumer. As Transit Leap vehicles are added, they are fully autonomous (level 5) from the outset, avoiding the uncertainty of wide-area infrastructure preparedness and the distracted driver problem that Google has noted.[12]

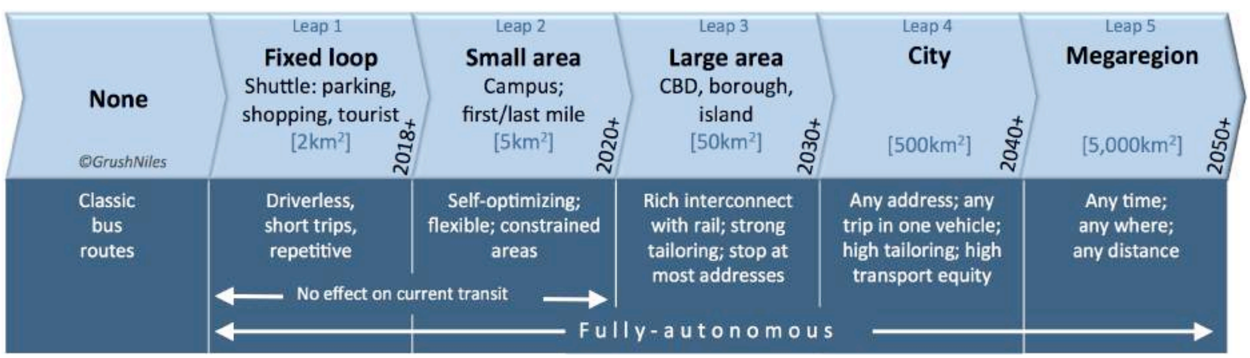

Figure 4: Transit Leap's stages are described spatially rather than as autonomy levels. All leap implementations require level 5-autonomy appropriate to their full spatial and climate domain. The maturity of each leap is enabled by the then-current reliability of level 5-vehicle operation.

Each stage would operate in accordance with evolving technology, without relative transit job loss (although job descriptions would change), and optimized to address current human preferences regarding owning and using automobiles. Beginning with first-and-last mile applications that fill an immediate, unaddressed need, Transit Leap progresses through larger and more capable roll-outs and ends with massive shared fleets that span megaregions after mid-century.

Leaps 1 and 2 can commence immediately. The use of level 5 automated minibuses to carry six to 12 passengers at slow speeds along carefully prepared routes has already been trialed in several countries. The CityMobil2 trials in the EU are the largest example.[13] Leaps 3 through 5 are rolled out over the ensuing decades in three additional overlapping, viral stages. As of this writing the technology is only ready for leaps 1 and 2, but the existence of numerous successful leaps 1 and 2 will soon engender a few modest leap 3s. Nothing drives innovation so much as adoption and markets. If a government wants to promote AV technology, adoption in operational applications is the best route.

Conclusion

At some foreseeable point—and a lot has to be resolved first[14]—we can imagine a world in which a self-driving vehicle can drive anywhere without constraint, i.e., anywhere a human-driven vehicle can legally drive. In such a world anyone might call up a robotaxi tailored in all respects to virtually any immediate purpose and would hence have diminished utility of owning a vehicle. This is the ideal world of Transportation as a Service (TaaS).

Robotic vehicle technology will not leave public transit undisturbed while it changes everything else about automobility. Rather robotics offers transit the choice of increasing service levels and ridership per dollar or being replaced with commercial TaaS. Transit must disrupt itself or be disrupted—Uberized as it has come to be known.

There is likely to be a long period of time before level 5 vehicles can be purchased by households and operated anywhere without constraint. In the interim, the technology will be able to operate with a high degree of reliability in constrained areas and initially at slow speeds in ways suitable to a small, then growing number of public applications.

The application of constrained level 5 vehicles (leaps 1 and 2) can at first complement transit, then begin (leaps 3 to 5) to disrupt it, growing ridership, confidence, markets, and jobs. If rolled out in ways to help households sell a second car or avoid buying a car, this can help dampen the revealed preference for vehicle ownership. Those regions that can deploy leap 3 areas within 15-20 years can expect to measure a significant increase in ridership and the beginning of a meaningful reduction in household ownership (not a relative plateau, but an absolute drop in spite of population growth). If whole cities can provide 7/24, rapid response, TaaS in 25-30 years—likely involving P3 financing and in collaboration with TNCs—the dominant preference for automotive ownership could be extinguished.

We (authors) would like to see cities and regions manage road congestion by having 20 percent of *vehicle trips* be in household vehicles and 80 percent in shared vehicles (including transit). If the shared vehicles were to handle (on average) four times the VKT compared to the average household vehicle, then cities and regions would remove fully 50% of the extant vehicles on its roads.

---

1 KPMG AV promotional video, https://www.youtube.com/watch?v=vg4TB10QO7Q
2 Grush, B., Niles, J., (2016) *Getting past the hype*, Thinking Highways, January. A copy is here: http://endofdriving.org/wp-content/uploads/2016/02/What-Gartner's-Technology-Hype-Cycle-teaches-us-about-the-autonomous-vehicle.pdf
3 Nieuwenhuijsen, J., (2015) A quantitative method to model the diffusion of automated vehicles with system dynamics. Delft University of Technology.
4 Nieuwenhuijsen, ibid.
5 KPMG, (2015) Me, my car, my life … in the ultraconnected age. kpmg.com/automotive.
6 Burns, L., Jordan, W., Scarborough, B., (2013) Transforming Personal Mobility. The Earth Institute, Columbia University
7 Fagnant D., Kockleman K. (2015) Dynamic Ride-Sharing And Optimal Fleet Sizing For A System Of Shared Autonomous Vehicles, Proceedings of the 94th Annual Meeting, TRB.
8 KPMG, ibid.
9 citymobil2.eu
10 Kay, J., (2015) *Uber v. Taxi: One must die to for the other to live*. The Walrus, September
11 http://www.pbs.org/wgbh/nova/next/tech/cities-autonomous-vehicles/
12 (2015) https://backchannel.com/how-to-make-moonshots-65845011a277#.1bxgggmse
13 citymobil2.eu
14 TU-Automotive, (2016), *'When' and 'how' now the biggest questions facing driverless vehicles.*