Application Creep:
Environmentally Sustainable Deployment for Autonomous Vehicles[1]

Bern Grush, John Niles, Grush Niles Associates, 2015

There are two popular and somewhat utopian views of the future of the self-driving automobile. One is a long-fantasized, extra safe, super convenient, congestion-busting household vehicle that requires no attention to operate. The other is an on-demand robo-cab that rolls up to wherever you are within a minute or two of your request via smartphone and zips you to exactly where you told the app you want to go.

Will one of these futures dominate or will they co-exist? Which future should a regional government prepare for?

David Levinson and Kevin Krizek open their new book: *The End of Traffic and the Future of Transport*[2] with:

> *"Day-to-day driving experiences are a stark contrast to the advertising spooled by auto makers. Driving is at best functional, and at worst a dangerous hassle. Commuting by car is failing to spur happiness. Complaints about traffic are increasingly widespread."*

While this description of automobility is hardly new, it is clearly our admitted cultural truth in contrast to our evident preference given what a century of advertising, film and other media have promised. Cities that report a constant stream of traffic woes on radio and newspaper are common. For decades, large cities throughout the world have been up against the wall of urban growth, congestion, rising costs, and environmental degradation. In tandem, many cities continue to have well-documented deficits in transit, road maintenance, and bike lanes.

Many observers believe the developed world is on the cusp of a tsunami of automotive innovation that will enable miraculous relief from these circumstances. Others think it more likely this will generate a new and different wave of problems. Precisely because it is easy to see how this could go either way, planning for the next 20 years given an expectation of impending vehicle robotics is wholly unlike any other 20-year planning exercise we might have engaged in over the past few decades.

Because the robotization of transportation vehicles is both certain and uncertain, infrastructure and transportation planning have been put at a new kind of disadvantage. Specifically, we can be quite certain of *someday(!)* needing no human operator for *nearly* all vehicles in *almost* all circumstances—i.e., pervasive vehicle autonomy. Many of us prognosticate about the nature of *some* of the disruption that will accompany this technology. But most of the robotic future is dominated by uncertainty.

We read many contradictory predictions about robotics vehicles. These are often biased: a manufacturer's spokesperson wanting to position their firm's brand; a Transportation Engineering PhD student simulating or extrapolating hopeful solutions to an enormous set of problems; a

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[1] This essay is based an appendix that appeared in "Building Our Tomorrow: The Future of Ontario's Infrastructure. How the impact of megatrends and rise of new infrastructure will change the province (and Canada)" by Michael Fenn, former Ontario Deputy Minister and founding CEO of Metrolinx and published in August 2015 by the Residential and Civil Construction Alliance of Ontario. It has been changed and extended.
[2] Levinson, D. and Krizek, K. (2015) *The End of Traffic and the Future of Transport*

safety engineer wanting to advance the life-and-death value of this technology as soon as possible; journalists awed by high-tech vehicle demonstrations they see at a trade show.[3]

Predicting vs. Hoping

All of this taken together leaves those charged with creating a regional or municipal transportation plan with many difficult questions.

How quickly will the autonomous vehicle arrive? No one can ascertain the speed or time of arrival of full, body-out, autonomy—i.e., full pervasiveness in a region or city. We can easily imagine *technical* feasibility in *most* operating circumstances, but we cannot say when sufficient reliability will be exhibited in *every* circumstance—indeed, some credible thought-leaders express doubts about this.[4] That means we don't know when (or if) any different sorts or scales of infrastructure will be needed, or how long what we might contemplate building in the interim will be needed.

Will robotics mean more or fewer vehicle kilometres traveled? Currently, humans are capped out at a worldwide average of about one travel-hour per day. If we can eat, play, sleep, read, work and shop instead of attending to driving, how much further might we choose to sprawl? Recent evidence appears equivocal. Many people who cannot drive now forego trips or have chauffeurs or use transit unwillingly. Will non-drivers with new freedom of mobility add to kilometres travelled, or increase the number of cars owned? This has been our behaviour for the past century.

Will robotics make travel cheaper? Humans now spend around eleven per cent of their disposable income on travel.[5] Robotics will lower the cost of the vehicle, its fuel, its insurance and its parking fees. When something is cheaper, more is consumed. Will the travel savings be spent on longer trips? Or on bigger vehicles as is common in North America now? One might think rational travelers would spend the windfall travel budget on something else, but that is true of only some people.

Will new automotive players change the solution landscape? Will incumbent automotive manufacturers continue to stage gradual innovations and very appealing safety features to sell more semi-robotic vehicles for more model years, or will new *apps-on-wheels* players like Google, Apple, Uber and Tesla steal the puck? Both types of players want to sell more. Some new players propose to sell kilometres or trips. The incumbents sell vehicles and some of them are already thinking about selling kilometres, too. Others envision giving away trips as long as passengers shop during or at the end of the trip. All of this means more vehicle kilometres would be consumed.

In what priority order will robotic vehicle technologies dominate? Will the auto industry focus on household vehicles before or after commercial vehicles and for-hire ride services? What about transit vehicles such as buses or vans? Expecting all autonomous applications to happen quickly—say over a decade—may be physically, operationally, and socially impractical. Will governments set regulations and let automotive manufacturers make and sell what they can to household consumers, while letting the insurance companies work out the issues of mixed traffic—driver-in and driver-out—sharing the road?

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[3] A recent report published by the Conference Board of Canada is an excellent resource. See *Automated Vehicles: The Coming of the Next Disruptive Technology* at http://www.cavcoe.com/articles/AV_rpt_2015-01.pdf

[4] Schwartz, Sam (2015) *Street Smart: The Rise of Cities and the Fall of Cars*

[5] Marchetti, C. (1994) *Anthropological Invariants in Travel Behaviour*, Technological Forecasting and Social Change, 47, 75-88. also http://en.wikipedia.org/wiki/Marchetti's_constant

Will shared fleets or household vehicles dominate? Critically, the jury is out on the matter of vehicle ownership, even though hope-filled forecasts by some paint a utopia of inevitable, widespread vehicle sharing. Will most autonomous vehicles be owned as family vehicles are now? Or will the advantages of shared fleets be available to, *evident* to, and selected by the great majority of travelers so that the population of household vehicles shrinks dramatically—90 per cent according to the most optimistic accounts? Will the car become more of a travel service and less of an accessory—i.e., all about the trip, nothing about status? Many academics are on record as saying "few people will own autonomous vehicles; most will share them", but there are many reasons—rational or not—that most people currently prefer or select ownership, even while a tiny-but-growing few have found ways to avoid owning a vehicle. The backdrop of culture, habit, status, privacy and convenience of owning can be stacked against the rational, economic notions of sharing and be used very effectively by automotive marketers. That has already started. Will irrational consumption or rational conservation dominate? New excess or a surfeit of sharing? It's impossible to know which future will prevail. We face many debates.

Some simulation-based research has been generated for cities such as Austin,[6] Lisbon,[7] Manhattan,[8] Stockholm[9] and others. Consistently, these researchers find that each simulated autonomous vehicle can replace about ten current, family-owned vehicles (that's where the "90 per cent" comes from). But these simulations are realistic only in a constrained context. They have been parameterized using the origin-destination (O-D) data collected in the simulated cities, but in most cases the researchers imply or reviewers conclude that such figures can be extrapolated to the world vehicle population. Ronald Bailey writes:[10]

> Researchers at the University of Texas, devising a **realistic** *[our emphasis]* simulation of vehicle use in [Austin] that took into account issues like congestion and rush-hour usage, found that each shared autonomous vehicle could replace eleven conventional vehicles. Notionally then, it would take only about 800 million vehicles to supply all the transportation services for 9 billion people. That figure is 200 million vehicles fewer than the current world fleet of 1 billion automobiles.
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> In the Texas simulations, riders waited an average of 18 seconds for a driverless vehicle to show up, and each vehicle served 31 to 41 travelers per day. Less than half of 1 per cent of travelers waited more than five minutes for a vehicle. In addition, shared autonomous vehicles would also cut an individual's average cost of travel by as much as 75 per cent in comparison to conventional driver-owned vehicles. This could actually lead to the contraction of the world's vehicle fleet as more people forgo the costs and hassles of ownership.

Does that 18-second *average* waiting time seem reasonable? There are several problems with these simulations and the conclusions most drawn from them. Research at Grush Niles Associates concludes that these simulations, constrained by the availability of useable O-D data, often contain unwarranted generalizations that cannot be reasonably extrapolated to suburbs and rural areas or work/service-related vehicles. Extrapolations such as echoed by Bailey must assume an inevitable and general willingness of all or most travelers to use shared vehicles. While there is much good to be said for a sharing economy, there is no evidence that all or most humans will engage this way. In fact, we can list dozens of barriers to such a general outcome. And we can also find ways to overcome some of these barriers to some degree.

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[6] 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. http://www.ce.utexas.edu/prof/kockelman/public_html/TRB15SAVswithDRSinAustin.pdf

[7] International Transport Forum (2015) *Urban Mobility System Upgrade: How shared self-driving cars could change city traffic*, Corporate Partnership Board, OECD

[8] Burns, L., Jordan, W., Scarborough, B., (2013) *Transforming Personal Mobility*. The Earth Institute, Columbia University

[9] Rigole, Pierre-Jean, (2014) *Study of a Shared Autonomous Vehicles Based Mobility Solution in Stockholm* (Masters Thesis)

[10] Bailey, R., *The End of Doom*, xxx

But it won't "just happen". We are dealing with humans who make many non-rational decisions based on personal, contextual or experiential criteria. In the coming decades, the success of the massive shared fleets these researchers simulate will depend more on revealed preferences and behavioral economics than on artificial intelligence.

What difference could robotics really make in the larger view?

We suspect that many would claim that the issues in owning versus sharing vehicles are a distant second to meeting the important challenge of getting to full automation in the first place.

We argue the reverse. Sharing is fundamentally more critical but generally obscured from initial view since full robotics is a prerequisite to the deployment of massive shared fleets. Most researchers and authors realistically focus on what comes first. An analogy to this occurred 110 years ago, when the car was hailed as the solution to the horse problem. Society dove headlong into full-bore automobile-centric planning and automobile user-preference as we pushed the horse out of our cities. There was neither understanding nor mitigation of the eventual global effects. 110 years ago we were largely unable to foresee these effects and paid little attention to the few warnings on offer. Of course humanity is free to repeat this error, and the likelihood of doing so is high, especially as there are some closer payoffs from status quo business models and ownership-thinking if we do. There is a lot of traditional motivation at play here.

Emissions are, at most, only 20 per cent of the problem. We often consider the climate cost of the fuel a vehicle burns to be the measure of its environmental footprint. This provides a superficial illusion that an all-electric vehicle using energy solely from renewables solves the problem. While useful in the marginal sense of the next trip that an individual might take later the same day, it is far from true if we consider a fleet that doubles every 20 years.

The embedded footprint from vehicle manufacturing and maintenance is equivalent to the first 150,000 km of an average fossil-fuel vehicle.[11] The distributed value of the entire parking infrastructure reserved for the North American car fleet exceeds the value of the entire vehicle fleet; and that carries an even larger footprint cost, as well. Add in the road, bridge and tunnel infrastructure that is being installed at breakneck speed in developing economies to support motorized vehicles, then include the current cost (implied footprint) of all the crash carnage to see the full cost were vehicle population to double twice more on the way to 2050. If parking infrastructure + road infrastructure + injury costs + manufacture & maintenance + emissions—five roughly equivalent environmental costs, P, R, I, M, E—are weighed in a full analysis, then the total environmental burden of automobility, even neglecting the costs of congestion, is easily five times the simple emissions/CO_2 burden environmentalists and journalists often focus on.

How can we turn such a large ship?

In spite of a plethora of unknowns—or perhaps because of it—regions and their surrounding municipalities can start now to develop policy direction that is more likely to make a desirable outcome of more sharing prevail than just hoping would do.

By waiting, municipalities risk the consequences of being swept up by exponential innovation that government will find hard to track, regulate and manage. Picking a winner would almost certainly be worse, as such a municipality would burn a lot of treasure before being swept away by further unexpected innovation. If Uber gave regulators headaches in 2013-2015, the disruption wrought by robotics by 2035 would be a thousand times worse. It bears repeating: the

[11] Berners-Lee, M., (2011) *How Bad Are Bananas? The Carbon Footprint of Everything*

20-year transportation future that starts now is harder to predict than any prior 20-year future since 1908.[12]

We know we cannot *build* our way out of congestion by simply deploying more of what we have built until now. And we know what we have now is inadequate to today's task. Without an ability to accurately predict the nature of motorized surface transportation vehicles in 2025, 2035 or 2045, we now cannot even *design* our way out of congestion. So how can Municipalities leverage all this innovation?

The only way to escape this conundrum is to *innovate* and *integrate* in order to find a better way through. We need to complement our notion of infrastructure to go far beyond physical facilities to encompass the methods, business models, vehicle access and use models, data and labour models that create transportation value. Road surface, tracks, heavy transit vehicles, schedules and routes will soon explain less and less of the total picture. Current preoccupations obscure our understanding.

As an example, the reason that so few people understand *prime time* or *surge* pricing from transportation network companies (TNCs), such as Lyft or Uber, is because most people see the drivers as chauffeurs—employees. But TNC drivers are not employees. They are volunteers. *Prime time* pricing calls them away from the dinner table, TV or their beds to drive in peak hours or at tavern closing times when rides are needed. The prior absence of such a ride pricing mechanism has meant that taxis are unavailable when most needed and circling pointlessly when they are not. Hence, the Lyft/Uber business model provides better service to its users, is cleaner for cities and encourages some users not to purchase a vehicle. It may also be cheaper than the bus in some ride-sharing circumstances, but this would likely remain a minuscule portion of passenger kilometers traveled.

Robotic vehicles, as indicated earlier, also have the potential to make big problems worse, especially congestion, sprawl, and a demand for even more traditional infrastructure such as roads and parking facilities. They will almost certainly wipe out any residual value in financially stressed public bus systems. As well, they would tend to entice away "choice riders", as Sam Schwartz warns:

> *It can become a vicious circle: the more transit becomes dominated by less affluent people, the more it becomes associated with poverty. And the more it gets associated with poverty, the less appealing it becomes for the affluent. Equity declines.* [13]

How should municipal and regional governments respond?

City governments that fight commercial, robotic, shared fleets—like some fought Uber—will lose. The cost per passenger kilometre on flexible, driverless vans, minibuses and robotaxis will be a tiny fraction of the same passenger kilometre on a bus. Some project as little as 25 per cent, but the jury is out on that, too.

Some pundits propose that cites or states set up testing grounds to be leaders and promoters for technology development. Why? City governments don't test pharmaceuticals. States and Provinces don't test new nanotechnologies. Why should they test robotic vehicles? Corporations do that.

Rather than test technology, local authorities should begin thinking through how their communities can encourage or even directly cause the building of large shared, robotic fleets

[12] Henry Ford announced the Model T in October 1, 1908.
[13] Schwartz, S. and W. Rosen, (2015) *Street Smart: The Rise of Cities and the Fall of Cars*

using P3 mechanisms. Local authorities should plan to disrupt their own public transit agencies head-on as a pathway to creating public robotic fleet services in a way that ensures equitable access for every citizen—a concept dangerously missing from the young, mid-chic, urban middle-class business model of today's TNCs.[14]

Today, at a time when the robotics are not yet ready, cities need to begin to create the pre-conditions for the future they want to create.

The Puzzle of Infrastructure for Robo-Cars

Two critical unknowns among all these uncertainties provide an important key to thinking about the infrastructure issues associated with robotic vehicles:

- Given many possible paths for policy, will the majority of autonomous vehicles be owned or shared?
- Will they be gradually mixed in with human-operated vehicles or will they be somehow isolated to carefully constrained, perceptually-safer applications?

Owned or shared? Private ownership will lead to large extant fleets. Since these vehicles will not require a licensed operator, young, old and disabled passengers can now utilize a dedicated vehicle without a family member acting as chauffer. Hence some families will see owning an additional vehicle as a very rational decision—and the powerful marketing forces of the automotive industry will always prefer the high-volume, well-featured consumption model stoked by year-over-year *feature-creep* to a shared-vehicle model.

Conversely, a shared-fleet model, if used by a majority of travelers, would mean smaller extant fleets, dramatically reduced parking infrastructure (and space), and less congestion. As written above, we could require less than 25 per cent of our present vehicle population to *operate concurrently*. However, there is no assumption of fewer vehicles *manufactured* since shared use means shorter life cycles—i.e., manufacturers will still make a similar (or greater) number of vehicles.[15] Once freed of cost of drivers, a larger fleet of smaller vehicles is far more flexible (and effective) for transit operations. Smaller, flexible fleets that offer better service at lower costs enables increased ridership. Increasing ridership, means increased employment. A fleet of shared vehicles of all configurations that (say) quadrupled ridership would certainly double employment. They just wouldn't be drivers. And this would happen over 20 years. Attrition and job-retraining are the solution, not layoffs and unemployment. Perhaps more people would work for P3 participants than be on the public payroll, but there is no need to lose jobs in this equation.

Freely mixed or constrained and isolated? There are many operational, social, and liability complexities involved in freely mixing driver-out and driver-in vehicles on the same roadway—the biggest elephant among the herd of elephants in this room being distracted driving.[16] Even if these become solvable, there are tougher acceptability issues. Furthermore, traditional automotive manufacturers will prefer the mixed model, as it justifies many years of new safety, intelligence, infotainment, status and convenience features, while nurturing an ongoing preference for ownership. They will continue to use behavioral economics in every conceivable way. And they will mine the rich marketing opportunities across the full spectrum of partial-to-complete robotic enablement, making driving in congestion more comfortable and taking advantage of the cultural predilection of "my car, my style, my way".

[14] http://fivethirtyeight.com/features/public-transit-should-be-ubers-new-best-friend/

[15] Wolfgang Schaefer (2014) http://www.planbeconomics.com/2014/11/continental-cfo-driverless-cars-by-2025.html (time= 6:40)

[16] Richtel, Matt (2014) *A Deadly Wandering: A Tale of Tragedy and Redemption in the Age of Attention*

Using increasing automation as a gold mine for adding new and compelling features to each model year is an example or the common commercial practice known as *feature creep*. Clearly many automated and safety-related features should not be disparaged as *feature creep*, but what *is* the same is the year-over-year business model of incrementalism that stokes envy and sustains sales. Traditional manufacturers will not readily abandon this underlying success formula for creating demand and maintaining competitive advantage. Who wouldn't?

New players such as Google, Apple, Uber and others promising full, driver-out, robotics sooner than the traditional players see feature creep as unworkable. Astro Teller of Google[x], (now under Alphabet) the business division overseeing the Google automated vehicle, at a keynote given at the South by Southwest Interactive in March 2015, says this best:

> Even though everyone who signed up for our [self-driving car] test swore up and down that they wouldn't do anything other than pay 100 per cent attention to the road, and knew that they'd be on camera the entire time…people do really stupid things when they're behind the wheel. They already do stupid things like texting when they're supposed to be 100 per cent in control…so imagine what happens when they think "the car's got it covered." It isn't pretty. Expecting a person to be a reliable backup for the system was a fallacy. Once people trust the system, they trust it. Our success was itself a failure. We came quickly to the conclusion that we needed to make it clear to ourselves that the human was not a reliable backup—the car had to always be able to handle the situation. And the best way to make that clear was to design a car with no steering wheel—a car that could drive itself all of the time.

This and other evidence[17] predicts that feature-creep will fail as vehicles become more automated. Well before becoming driver-out, a jump to full autonomy will be demanded. But we cannot move to pervasive robotics quickly. We'll need to *creep* our way there, as well.

Teller's comment also predicts problems for mixing autonomous and non-autonomous vehicles. Collisions involving Google's autonomous vehicle operations to-date have mostly been blamed on drivers of ordinary vehicles, who rear-ended the Google cars. It may be that autonomous cars conform to speed limits more consistently or tend to stop more frequently or more suddenly and than do human-controlled cars.[18]

Application Creep

If driver-in/driver-out mixing is going to be problematic, it would make much more sense to put robotic vehicles to work earlier in constrained, un-mixed applications.

For this path to the future, we introduce the term *Application Creep*, which focuses on lower risk, partially isolated applications with which we can begin cautiously: start out highly constrained and incorporate extreme oversight, before branching out and eventually disrupting traditional transit. The EU's CityMobil2, a small-vehicle test project in several cities, is an early example. Notably, these pilots also include research into financial, cultural, and behavioural aspects as well as effects on land use policies and how the new systems mesh with existing infrastructure.[19]

There are many other smaller-scale, spatially constrained applications such as military, university and employment center campuses. Parking lot shuttles at airports could be serviced by six- or ten-passenger vehicles running at modest speeds on clearly marked lanes (self-guided only) and tightly constrained to regular service on regular routes. Retirement communities could use such vehicles for local on-demand trips including to local shopping, entertainment and worship, with the vehicles beginning to determine best routes, rather than being constrained to fixed routes.

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[17] Richtel, Matt (2014) *A Deadly Wandering: A Tale of Tragedy and Redemption in the Age of Attention*
[18] http://www.nytimes.com/2015/09/02/technology/personaltech/google-says-its-not-the-driverless-cars-fault-its-other-drivers.html?
[19] http://www.citymobil2.eu/en/About-CityMobil2/Overview/

Human attendants could be eased out only gradually, in order to provide continuity and comfort to early users and to help address changing labour demands. Such applications are numerous, can start almost immediately, and can be gradually expanded (hence *creep*) to include longer routes, allowances to handle passenger requests by smart phone (more like a jitney than a shuttle), and to increase route flexibility, length and detail.

Urban areas could begin with smaller (shorter, simpler) bus routes at low speeds on constrained lanes at grade and without barriers, set up like bicycle lanes. If adjacent lanes carry driver-in motorcars, they would be traffic-calmed. These city systems would benefit from the experience of the earlier parking shuttles, campus applications and the retirement communities. This would indicate a degree of local government interest in supporting these earliest systems. City transit routes could expand in number, distance and flexibility—until transit is dominated by *multi-sized* autonomous vehicles and each is scaled to purpose ("tailored").[20] During the latter half of this shift, robo-taxi services could begin and would merge so that robo-taxi and robo-transit are on a continuous service spectrum.

Lvl	Name	Definition	Tailoring	Network/Reach	PKT
1	Loop (started)	Vehicles on **limited, repetitive, fixed**-route, fixed schedule routes of short duration, under 30 mins, under 10 km, under 20kph	Little or none: Vans, minibuses	Shuttle: parking, shopping, urban tourist 2km^2	<1%
2	Small Area (2025)	Vehicles operating on most/ all roadways/routes in a **constrained area**. Vehicles self-optimize routes depending on combination of schedule performance and user-demand responds to individuals calling for service by origin and destination	Modest: vehicles from 2 to 8 passengers; shuttles, taxis, TNCs, minibuses; modest optimization of vehicle assignment. Start of P3s.	Campus: corporate, university, military, retirement community. First-mile and last mile to/from train stations or transit hubs. 5km^2	3%
3	Large Area (2035)	Same as Level 2, plus vehicles operating on most/ all roadways/routes in an **urban subarea/district**	Full: vehicles from 2 to 30 passengers. At least 3 competing fleets; at least 2/3 are P3s.	Borough, suburban or exurban area, CBD, Island. 50km^2	15%
4	Regional (2045)	As level 3, plus **anywhere, any distance**, public roads	Full: vehicles from 1 to 100+ passengers; Majority P3s	City. 500km^2	40%
5	National (2055)	As level 4, plus any mapped private roadways	Full; Majority P3s	Megaregion. 5000km^2	80%

Table 1: These five levels of Application Creep or Levels of Reach are five stages of spatial reach, each absorbing the prior stage, and eventually blending into spatially continuous, fully pervasive automation over increasingly larger areas until they bleed together. Level 1 starts with very small, independent local applications and ends at Level 5—essentially nationwide. This would take 30-40 years. The same amount of time it took the motorcar to completely displace the horse. This is distinct from the five SAE levels of Feature Creep involving increasing levels of automation: [L1] driver assistance, [L2] partial automation, [L3] conditional automation, [L4] high automation, and [L5] full automation. The major difference is that the vehicles deployed in the gradually growing spatial applications would all be SAE level 5 from the first day.

[20] Burns, L., Jordan, W., Scarborough, B., (2013) Transforming Personal Mobility. The Earth Institute, Columbia University.

The constrained, protected spatial applications allow greater technical autonomy, turning drivers into trip assistants and guides from day one.

Innovation and Integration

We can now reasonably begin the process of deciding how robotic mobility technology—especially where it involves sharable components—is to be deployed. We want to use this technology to completely transform surface transportation from transit that is cripplingly expensive and used across all trip types for five to seven per cent of passenger kilometres in the US and Canada. Shared vehicles (taxicabs, transportation network companies, and carshare) although growing in number now, still produce statistically miniscule passenger kilometres on a North American basis. Private vehicles—idle 95 per cent of the time—handle about 93 to 95 per cent of passenger kilometres in Canada and USA, respectively.

GNA research indicates that setting and beginning work on a long-run target of 80 per cent of all passenger kilometres to be traveled in shared vehicles—i.e., vehicles that belong to public, private or co-op fleets and that are busy from 40 to 80 hours per week instead of only eight or nine hours—should motivate an urban region to the point where a community of business and government leaders could begin to innovate just how such a fleet could be financed, maintained, managed and priced. Leaders could begin to figure out how to park this fleet off peak, how to power it, how to re-purpose the liberated parking areas. Real estate interests in the community could begin a process to decide how to turn parking garages to other uses or re-purpose parking lots as parks or building sites. Planners and public works departments might convert street parking to bicycle paths. If community leaders do not set such an assertive target, automotive manufacturers will continue to operate a high, personal-vehicle consumption model with unfortunate results for our cities.

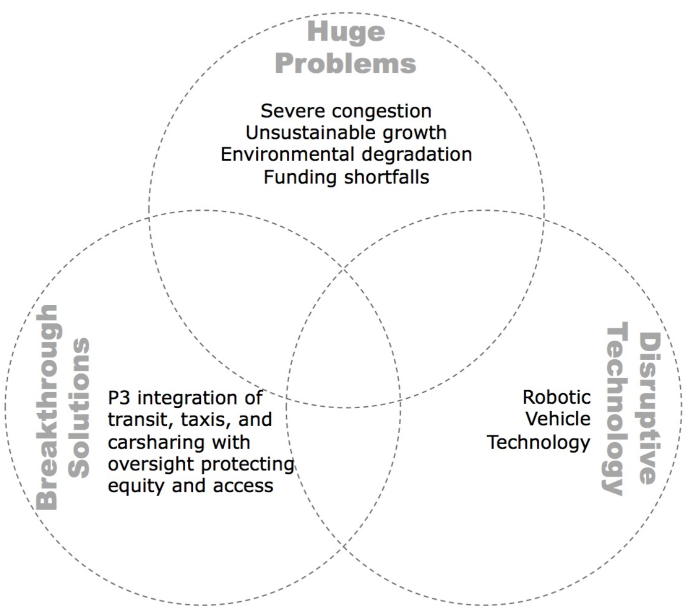

Figure 1. Public-Private Partnerships for Innovation could create opportunities for regions to ensure access and equity to all and enormous opportunities for manufacturing and jobs. *[The model for this diagram was inspired by a drawing accompanying an online presentation by Astro Teller of Goggle[x].]*

Communities should start thinking now who would be best to deploy such fleets. Without going to specifics at this stage, it's not too early to begin forums to discuss the incentive and regulatory structures that would fit community or regional values. Ideas should be collected regarding ownership models that would make sense. The alternatives of fleets owned and managed by large corporations à la the Wal-Mart model or franchised as family-run fleet clusters on the McDonalds model should be put into planning scenarios. Universities and professional groups should be asked to think about a role in sponsoring affinity fleets run by co-op transportation operators. What kinds of government guides for pricing, service, response times will be needed to maintain equity, or can the forces of the competitive market include motivations for sustainable social and transportation equity in some unexpected ways? All this, and more, is worth discussing now in government-business forums.

The real disruption

The difference between the incremental *feature-creep* model normally pursued by auto manufacturers and the disruptive model of moving directly from driving to not driving as is being pursued by Google, the EU, and others is the difference that holds a key to the solution we are seeking. There are numerous problems of mixing robotic driven and human driven vehicles at any ratio—whether 1 per cent, 50 per cent or 99 per cent. Adopting an incremental, gradual, mixed-traffic model would lead to years of contention regarding traffic rules, overly cautious robotics, insurance liability, ethics conundrums, and new legions of distracted drivers using robotics that operate for 90 or 99 but not 100 per cent of a trip.

If cities emphasized full-solution, *application-creep* innovation instead of preparing or waiting for household-vehicle feature-creep from the auto industry, less contentious, incremental improvements would emerge in controlled, planned circumstances. If public agencies used innovative business and financing models to replace and grow public (transit) passenger kilometres in increments safe for passengers and in ways that allow for thoughtful mitigation of the forthcoming, inevitable labour disruption, we could reduce the subsidization burden of transit, grow its ridership, and attract riders out of household vehicles, in the same way TNCs do now. Rather than resisted, TNCs should be groomed and regulated so as to be integrated into a new hybrid solution of privately operated fleets governed for accessibility and equity. It is the current case that however much Lyft and Uber may be good for young, car-less travelers in our cities, TNC services are not designed to be available to the poorest travelers. Cities have a critical role to ensure access and equity, especially as current transit methods and technologies are disrupted.

With multiple service levels keyed to variables such as vehicle age, ride features, number of stops, ride sharing, convenience, comfort, and more, a range of prices can be supported to be affordable for all users. There are ways with very little subsidy—very little would be best—to have transportation available to everyone at a level affordable for each. This is a preferred future.

Transportation leaders in the developed world where private automobile ownership is the highest should lead the way in establishing a clear direction toward a preferred future of massively-used, massively-shared robotic fleets. Benefits will come from demonstrating sustainable, environmentally-friendly models of urban style and fashion for the rest of the world to imitate as vehicle automation emerges in practice.

Finally, there is no way to predict all of the effects robotic mobility will have on the future of urban spatial distribution: density and sprawl. This is because the future unfolds based on technology, policy and wealth—a mix that cannot be pre-determined. The harder truth is that what we believe we are able to predict about this new technology is less important than what we don't know or have not yet imagined. The things we surmise now about safety, productivity and labour disruption or the things we hope about congestion, energy efficiency and parking space recovery are easy enough to imagine. But many other aspects of the future such as how we will locate ourselves in this re-enabled landscape, how transportation business and equity models will change or could be regulated, and how we will think about and finance the infrastructure needed to hold all this together, are much harder to contemplate.

And these things also need attention. Starting now. ■