

An Independent Study
Commissioned by



RESIDENTIAL AND
CIVIL
CONSTRUCTION
ALLIANCE OF
ONTARIO

Constructing Ontario's Future



Ontario Must Prepare for Vehicle Automation Part 2

How Skilled Governance
Can Influence its Outcome



RCCAO

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The Residential and Civil Construction Alliance of Ontario (RCCAO) is composed of management and labour groups that represent a wide spectrum of the Ontario construction industry.

The RCCAO's goal is to work in cooperation with governments and related stakeholders to offer realistic solutions to a variety of challenges facing the construction industry and which also have wider societal benefits.

RCCAO has independently commissioned 46 reports on planning, procuring, financing and building infrastructure, and we have submitted position papers to politicians and staff to help influence government decisions.

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Ontario Must Prepare for Vehicle Automation Part 2

How Skilled Governance Can Influence its Outcome

An independent research study prepared for the Residential
and Civil Construction Alliance of Ontario (RCCAO)

By Bern Grush, Grush Niles Strategic with John Niles
(collaborating author) and Blair Schlechter (contributing author)

OCTOBER 2017

Author and Acknowledgments

Bern Grush is a Toronto author, speaker, systems thinker, futurist and entrepreneur focused on transportation demand management. He is the co-author (with John Niles) of the upcoming Elsevier book *The End of Driving: Transportation Systems and Public Policy Planning for Autonomous Vehicles*. He is the author of the blog endofdriving.org, drawing attention to urban and social issues around the deployment of automated vehicles. Before that Mr. Grush authored grushhour.com, which focused on congestion charging and parking pricing. He is a co-founder of PayBySky and has been working with MaaS Global (Helsinki) to bring their Mobility as a Service (MaaS) app, Whim, to Canada.

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Conversations and email exchanges on the topics of this report with numerous government and business leaders worldwide have made it a much better report — an appreciative thanks to all.

The viewpoints expressed herein are those of the author and not necessarily those of RCCAO, the reviewers or other contributors, nor of any organizations with which Mr. Grush is associated. Any viewpoints expressed by Mr. Schlecter in Chapter 6 are solely his and not those of the Beverly Hills Chamber of Commerce. Any errors or shortcomings in the report are entirely the responsibility of the first author.

“Change is occurring more quickly than I thought. And the world in which we live is more complicated than I thought. We are living at a hinge point, not just in our own history but in the history of the world. It’s an age of disruption marked by powerful global trends. Globalization, the fourth industrial revolution, climate change, demographic change, challenges in governance and the rise of distrust in many of our institutions are reshaping our world in fundamental ways.”

— David Johnston
28th Governor-General of Canada
Globe and Mail, September 29, 2017

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Mr. Phillip Rubinoff
Chair
Mr. Andy Manahan
Executive Director
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Dear Messrs. Rubinoff and Manahan:

Thank you for your letter and report regarding automated vehicles (AVs) in Ontario. I appreciate RCCAO's contribution and research activities on this important topic and I apologize for the delay in responding.

The government recognizes the importance of new vehicle technologies, especially those that can expand mobility options and create economic opportunities for Ontarians. Ontario is well-positioned to be a global leader in the development, testing and deployment of AVs and is taking steps to secure that role.

For example, on January 1, 2016, Ontario launched a new pilot program – the first in Canada – to allow for the testing of AVs on Ontario's roads by eligible participants under certain conditions. At this time, participation in the pilot is limited to auto manufacturers defined within Canada's *Motor Vehicle Safety Act*, technology companies, academic and research institutions and a manufacturer of parts, systems, equipment or components for automated driving systems.

A pilot phase also allows the Ministry of Transportation (MTO) to establish rules, monitor industry developments, and evaluate the safety of AVs prior to them becoming widely available for public use. On an ongoing basis, MTO will assess the data and information gathered from testing the on-road use of AVs and make amendments to the pilot framework as required.

While it may be too early to determine what adoption models will occur, the concepts put forward in the report you provided will be carefully considered as we undertake our policy work. To prepare for a future that includes AVs, MTO will continue to engage with municipalities, the federal government and other stakeholders to consider potential scenarios and optimal adoption models for AVs. For instance, as part of the Greater Golden Horseshoe (GGH) Plan, MTO will be assessing potential impacts of AVs and the readiness of our transportation systems in light of such impacts.

In addition, the province has made investments to support automated vehicle development in Ontario, including nearly \$3 million since 2014 through the Ontario Centres of Excellence's Connected Vehicle/Automated Vehicle (CV/AV) Program, to promote Ontario-based industry partnerships.

Looking forward, the province remains committed to supporting growth in this sector and recently announced in the 2017 Ontario Budget that we are investing \$80 million over five years to create the Autonomous Vehicle Innovation Network, in partnership with Ontario Centres of Excellence. This initiative will capitalize on the economic potential of CV/AVs and help the province's transportation systems and infrastructure plan for and adapt to CV/AV technology.

For more information about this initiative, I suggest you contact Raed Kadri, Director, Automotive Technology and Mobility Innovation at the Ontario Centres of Excellence at raed.kadri@oce-ontario.org.

MTO is committed to fostering a policy and regulatory framework that promotes economic growth and innovation while protecting road safety in Ontario. We continue to consult key stakeholders, review research (including reports such as yours), and monitor ongoing developments related to this technology.

Thank you again for your interest in the success of automated vehicle technology in Ontario, and for your contributions to this exciting field.

Sincerely,



Steven Del Duca
Minister

c. The Honourable Kathleen Wynne, Premier of Ontario



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Ontario Must Prepare for Vehicle Automation

Automated vehicles can
influence urban form, congestion
and infrastructure delivery

Ontario has an opportunity to develop and test automated vehicle (AV) deployments that will shape the future of our road infrastructure, our commuting patterns and transit delivery.

With the hype surrounding AVs, RCCAO commissioned Bern Grush, a leading systems thinker, to research the potential impacts. While there are many future scenarios, Mr. Grush recommended that the Ontario government facilitate pilot projects to test these new technologies to address our stubborn congestion problems.

AVs touch almost every aspect of our lives: transportation of people and goods; change in the nature and management of transit; congestion; land use (both policies and pressures); safety; public health; labour ... but most importantly for Ontario – manufacturing, trade and innovation.

This report highlights the rise of two competing markets for AVs: semi-automated vehicles, primarily for personal use, and fully automated vehicles, comprised mainly of robo-taxis and robo-shuttles for public access.

As these two formats gradually replace the ranks of the non-automated vehicles we use now, urban form will change and Ontario will have to adapt to new traffic patterns – especially in the GTHA. The decisions the province makes over the next decade as this technology becomes pervasive will be critical to Ontario's future success. A doubling of road capacity will be possible with the use of narrower lanes and shorter headways between vehicles. Coordinated streams of connected vehicles will be able to pass through intersections without traffic signals impeding flow.

This report explains what needs to happen before the rise of the automated vehicle, which we will begin seeing on our roads in the early 2020s.

"... our government believes that Ontario's innovation ecosystem with leading clusters in automotive, information technology, and cleantech, makes the province the ideal location to develop the disruptive technologies like AVs that will shape the future of the industry."

Ontario Premier **Kathleen Wynne**,
in letter to RCCAO after receiving this report

"Everyone involved with planning the transportation infrastructure for the next 40 years should download and read this very important study."
Robert W. Poole, Jr.,
Reason Foundation

"Bravo! This is a really excellent report."
Alain L. Kornhauser,
PhD, Faculty Chair,
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THE EDITORIAL

Understanding the future of driverless cars is crucial to navigating present concerns regarding infrastructure and public transit

MAPPING THE FUTURE of driverless cars is much like surviving the morning commute today. We know where we want to go, but getting there quickly is the problem.

The prospect of fully autonomous cars zipping along while passengers snooze, work or otherwise ignore the road is a widely anticipated utopian dream. A world of driverless cars means roads that are safer and less congested, workers who are more productive, cheaper housing options and greater mobility for the elderly and for people with disabilities. It seems a tantalizing future. Yet despite well-publicized tests of driverless cars in Pittsburgh, Sweden and elsewhere, the arrival of this transportation nirvana is still a long way off. Most people with driver's licences today will never know the full delights of driverless roads. In the meantime, understanding how this future is likely to unfurl is crucial to navigating our present.

A fascinating and carefully argued report released last month by the Residential and Civil Construction Alliance of Ontario argues that it will take many decades to achieve the sci-fi world of self-driving vehicles, and that it will roll out in a chaotic and often frustrating manner. Due to established consumer habits, sluggish government regulation and existing infrastructure, between now and 2050 Canada's roads will be dominated by semi-autonomous vehicles, says report author Bern Grush. These are cars with a panoply of technological features, some of which are already available, such as adaptive cruise control, lane recognition and automatic emergency braking, that make driving safer. Despite these advances, however, they'll still require a driver behind the wheel, if only to take charge in special circumstances.

Fully autonomous vehicles—cars that drive themselves without any human input—will lag much farther behind in acceptance because of the technology involved and the fact they represent a far more dramatic departure from the status quo. Grush predicts these vehicles will first establish themselves in the realm of public transit: robo-buses travelling on fixed routes. Not until the second half of the century will driverless cars finally come to dominate travel for personal use.

Understanding the tension between these two competing technologies will be crucial to finding our way for the next 40 years. For starters, things are likely to get worse before they get better. Drivers' initial preference for privately owned, semi-autonomous cars will

inevitably result in more vehicles on the road, more overall kilometres travelled, greater demand for downtown parking, fewer bus trips and increasing competition and conflict between drivers and other road users over such things as urban bike lanes. "Congestion will remain an issue for the foreseeable future," counsels Grush.

A grander vision of the future in which fleets of fully autonomous cars pick up and drop off passengers wherever and whenever they wish will take much longer to arrive because it must overcome generations of embedded consumer behaviour and institutional inertia. Most significant, it will mark the end of the long-standing association between private car ownership and personal freedom. This transition "will take longer and be more painful" than most people appreciate, Grush warns. By the time the world of fully autonomous cars is finally realized, today's Millennials will probably be entering their sixties.

Such a long changeover period suggests some big dilemmas for present-day governments. Current efforts to constrain suburban sprawl around big cities may be pushing uphill against both technology and basic human desires. If it is the destiny of driverless cars to enable longer and more pleasant commutes, then we can expect sprawl to grow, not shrink, over time. And the prospect of an imminent worsening in congestion suggests more resources need to be directed to road-building. Both conclusions conflict with ideology currently popular among urban planners that reveres high-density living and public transit.

In fact, conventional public transit is likely to be the earliest casualty of driverless cars. Fully autonomous robo-buses, which could be operated privately, look set to disrupt traditional bus routes in the same manner as Uber has already disrupted the taxi business: it will be cheaper and more convenient. And further, the federal government is planning to spend \$120 billion over the next decade on infrastructure, a third of which is expected to be dedicated to big-ticket public transit projects such as light-rail transit and subways, projects with lifespans measured over many decades. But will we still be using fixed-rail transportation 20 years from now? And if not, would that money be better spent elsewhere?

It took nearly 40 years for the horse-drawn world to fully transition to an era of internal combustion engines. The switch to driverless cars will likely take just as long. So buckle up. It's going to be a long trip, but it'll be worth it in the end. ♦

A grander vision of a future with fully autonomous cars must overcome generations of embedded consumer behaviour and institutional inertia

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1.0 EXECUTIVE SUMMARY



The movement of people and goods throughout the Greater Toronto and Hamilton Area (GTHA) — and the rest of the developed world — is being digitized, disrupted and democratized. [Friedman] The emergence of e-commerce is transforming a growing portion of personal shopping trips into courier delivery trips — 9.5 per cent in Canada. Digitization makes telework easier, which has contributed to a reduction in *relative* commuter trip demands. But the changes wrought by the smartphone — transit, taxi and ride-hailing apps, parking finders, and payment apps — is only the beginning. Mobility on Demand smartphone apps that bundle multiple modalities with user and provider reputations as well as with payment management systems will begin to disrupt car ownership in the early 2020s, especially if we pave the way for common adoption of the on-demand robo-taxi systems. These are widely forecast to arrive in cities during the 2020s.

With **digitization** comes capabilities, data, opportunities and innovations that are hard to anticipate — and even harder to prepare for. What was an easy question only a short time ago — how many car parking floors should a high-rise developer build? — has suddenly become a multi-million dollar executive quandary now with its own professional-planning conference sessions. Dozens of similar disruptions have been forecast.

With **disruption** comes job changes, altered infrastructure demands, new businesses and lost businesses, and unexpected opportunities for urban planners, along with government revenue losses as fleets that are electrified and automated yield less fuel, parking and ticketing revenue.

With **democratization** comes more mobility options everywhere, more convenience, new business formats, and eventually lower prices. What was unlikely becomes tenable. A few years ago, two strangers sharing a ride was a fringe idea, statistically invisible on transportation charts even if reported in a small number of urban corridors. Since then, ride-hailers have popularized the idea, and it now appears like a workable approach. Even New York City taxis started to offer ride sharing in 2017.

And democratization feeds back into more disruption, compounding the cycle. Uber and Lyft have disrupted the taxi industry and started to disrupt transit ridership in cities such as New York, San Francisco, Denver and Las Vegas, at the same time encouraging some smaller cities and towns to collaborate with ride-hailers in a bid to be relieved of unaffordable bus routes. This cycle is vicious or virtuous depending on your perspective. The more transit is disrupted, the more ridership is lost, the more routes need to be trimmed back and the more ride-hailers are asked to take over.¹ And all of this portends complex social, employment and environmental justice considerations, even as it provides an opportunity to shift public money to more robust trunk lines fed by short-haul robo-taxis and robo-shuttles.

The year 2030 is predicted to bring to the GTHA a level of vehicle automation sufficiently pervasive to provide at least one-quarter of all passenger kilometres travelled (PKT) in driverless robo-taxis and robo-shuttles. Of course, this projection assumes these vehicles will be common by then, and that there is openness to and readiness for deployment. Given a projected GTHA population of 8.5 million by 2030, this would be mean just over 12.75 billion vehicle kilometres at current travel rates and an average occupancy of 2.0 in two- to 12-passenger vehicles. At current average urban speeds and with an optimized fleet schedule, this would require a combined fleet comprising $150,000 \pm 20,000$ vehicles — presumably mostly electric and predominantly under commercial management.

The context for this report considers several threats including:

- Massive, commercial, electric and automated fleets using public rights-of-way without paying fuel taxes.
- Public bus systems under severe competitive threat; bus fleets replaced (or displaced) by higher counts of smaller commercial micro-transit vehicles.
- More outward growth due to uptake of personal semi-automated vehicles, expected to be mostly electric.
- Insufficient incentives for passengers to start or end robo journeys at transit hubs, meaning a drop in transit ridership and growing small vehicle swarms.
- Organized labour concerns about job losses, or job changes that may lead to declining compensation and working conditions.
- Population growth increasing urban travel demand and challenging the touted congestion advantages of vehicle automation.

This report provides much evidence that government agencies will not be able to sustain Ontario's current bus transit systems through 2030 by fighting to keep them viable with increased funding, changing fares or even improving payment systems. Digitization, disruption and democratization will prevent that.

This report culminates with a proposal for cloud-based transportation management that would:

- Encourage robo-taxi connections to transit hubs, especially rail stations.
- Support planning for related infrastructure changes.
- Improve locational access, including service areas and job reach.
- Increase trip availability to all citizens and income groups, including those with accessibility challenges.
- Improve travel patterns by expanding the reach of flexible service routes and associated trip availability.
- Nudge increases in vehicle occupancy in robo fleets, i.e., motivate more ride-sharing.
- Support aging in place.
- Minimize parking, circling, deadheading and emissions.
- Prepare for attrition of current bus transit.

1.1 Recommendations

This report recommends that our regional and municipal bus transit authorities move from an acquire-and-operate mode to one of specify-and-regulate. There are two key and menacing drawbacks to an acquire-and-operate approach. First, we are entering an era in which technology is changing faster than any government agency can respond, meaning that the risk associated with choosing, acquiring and deploying rapidly innovated automated transportation systems becomes untenable. A March 2017 staff report from the Toronto Transit Commission illustrates this, as detailed in this report. Second, the cost of new systems, new infrastructure and attrition of existing systems is out of taxpayer reach without commercial involvement if we are to move dramatically away from household car ownership.

Finally, this report recommends a way to specify and regulate growing fleets that is focused entirely on optimization and inclusion. This involves licensing regulated operators to manage fleets under government social-performance criteria. These fleet operators would be free to innovate vehicles, services and prices — subject to safety, privacy and security certification. Beyond performance criteria and certifications, this approach represents an all-digital market system managed via fees and subsidies based entirely on social performance metrics. It is critical that all segments of urban society be served by this “new mobility.”

2.0 INTRODUCTION: A PLANNER'S SUMMARY

**Governments and commercial operators
can work together to create a system that
enhances our mobility options in a future AV-world.**



This image taken from the YouTube video related to this report found at rccao.com

This report is the second instalment in the RCCAO series *Ontario Must Prepare for Vehicle Automation*. It seeks a path through a minefield of contradictory predictions and extraordinary promises about automation to shed light on the reasons the urban and infrastructure-planning problem is as difficult as it is important. From there, it proposes an actionable solution that does not require waiting until the technological innovations come into clearer focus.

For more than a decade, it has been common to forecast that most things about automobility will soon be automated and that this will enable remarkable change. It has been predicted often and enthusiastically that we will experience a reduction in accidents, parking, lane width, congestion, the tedium of commuting as well as innumerable other benefits. There have been counter projections describing road traffic and sprawl getting worse. The task of this report and its predecessor is to prescribe solutions while assuming all these projections — utopian and dystopian — are plausible.

Part I of the RCCAO vehicle automation series culminated in a hardware approach, “Transit Leap.” [Grush, 2016] This proposed the staged deployment of massive micro-transit and robo-taxi fleets. [See Ch. 9, appendix]

Part II — this report — explores a software approach, the “Harmonization Management System” (HMS). This envisions a digital management approach specifically geared to address the less-explored threat of massive commercial fleets disrupting public transit systems, which in its worst case would deny public transit agencies their critical role in optimization and inclusion.

While the approaches of Transit Leap and the Harmonization Management System can operate collaboratively or independently, Harmonization Manager is by far the most powerful and least costly solution for government coping with the coming mobility innovations. It would be the solution of choice for any region struggling with planning and funding changes to manage or accommodate driverless mobility.

2.1 Forecasts: Hope, Hype and Exaggeration

Of the many recent automated vehicle publications, the highly cited report from RethinkX [Arbib] has been among the most comprehensive, speculative, alarming and attention-grabbing. Its authors outline a trajectory for vehicle automation and its knock-on effects that may well be reasonable, but its timeline is wildly optimistic, dramatically overstating how quickly fully automated (SAE level 5²) vehicles will be commercialized and how rapidly their adoption will diffuse (95 per cent of all U.S. PKT by 2030)³.

What is far more likely is that a growing portion of PKT by 2030 will be a combination of (1) conditionally automated, level 3 vehicles that will remain household vehicles since they require licensed drivers, and (2) level 4 driverless vehicles constrained to low speeds in geo-fenced areas (robo-taxis). This will describe the next 30 or more years until driverless, unconstrained level 5 vehicles capable of, and regulated for, travel anywhere under any circumstances and at any posted speed become viable. [Ch. 4]

The outcome of rapid deployment of on-demand robo-fleets reaching the majority PKT penetration described by RethinkX [Arbib] will be stretched out — by at least an additional 20 years — i.e., to 2050 from 2030. This matches the Transit Leap approach. But rest assured, the disruption RethinkX describes will start, even if it proceeds more slowly. And it will not require a projected 95 per cent of PKT in on-demand robo-vehicles to strand oil assets and disrupt manufacturing, which are among the principal concerns of the RethinkX authors. Just a 20- to 25-per-cent PKT penetration by 2030 in the GTHA can severely disrupt current municipal bus systems. [Ch. 3.10] And this level of diffusion is virtually certain since this percentage merely shifts the existing non-private trip services (taxi, bus, Uber, carshare) to constrained, on-demand driverless services concurrent with a modest fraction of two-car households becoming one-car households.

Compared with what RethinkX describes, North America will experience a longer period of disruption with a greater churn of mixed driving, more cycles of regulatory changes, more and increasingly expensive tentative infrastructure decisions (including the repeated indecision common in some regions, including the GTHA), and a longer period of interim, chronic pain. Will we be in better or worse shape to take 33 years instead of 13 years to reach the driverless (Level 4) diffusion RethinkX describes?

This report argues that the path to get to a RethinkX utopia will be more difficult and will take longer. It proposes a new way to prepare the GTHA for the role of optimization and preservation of social inclusion for regional transportation infrastructure, an approach making the hoped-for utopia more likely. [Ch. 6 and 7]

2.2 Acquire-and-Operate vs. Specify-and-Regulate

The arrival of automated motor vehicles will touch almost every aspect of regional governance: transportation of people and goods, change in the nature and management of transit, congestion, land use (both policies and pressures), safety, public health, aging in place, environment, labour and, in some jurisdictions, even manufacturing, trade and innovation. The latter is an important differentiator for Ontario, because of the significance of the automotive parts and assembly industry in the province.

The outputs of private sector investment and innovation in automated and connected vehicles and systems will generate consumer markets for both vehicles and rides that will demand a considerable turnover of related infrastructural and regulatory responses. The responses generated will further and guide, or distort and hinder the effects of changes wrought by automation. Even a non-response will have consequences or repercussions.

The predecessor to this report — subtitled “Automated Vehicles Can Influence Urban Form, Congestion and Infrastructure Delivery” — delineated the critical nature of two different and competing markets for vehicle automation, how these markets would likely play out and the impact this would have on congestion, transit, land-use demands and traffic management over the two to three decades commencing in 2020. [Grush, 2016]

The 2016 report emphasized Transit Leap⁴ as a hands-on, government-regulated infrastructural response that described a way to track and leverage the “new mobility” technologies of automated and connected vehicles in a direct, physical, acquire-and-operate mode — possibly with P3 involvement. In this approach, local and regional governments would directly invest in and oversee a series of increasingly sophisticated stages of public transportation provision — each stage of which would develop greater reach, convenience, affordability and speed, as the technology allowed, until the entire GTHA would be provisioned for shared vehicles and shared ridership that would be optimized and scaled for full inclusion by mid-century. This is predominantly a “hardware” approach.

There are two key drawbacks to an acquire-and-operate, hardware-focused approach. The first is that we are entering an era in which technology will change faster than most governments can respond, meaning that the risk associated with acquiring and deploying automated transportation systems as these become digital-centric is rapidly becoming untenable.⁵ The second drawback is that the cumulative costs of new systems, new infrastructure and attrition of existing systems is out of taxpayer reach without public-private cooperation.

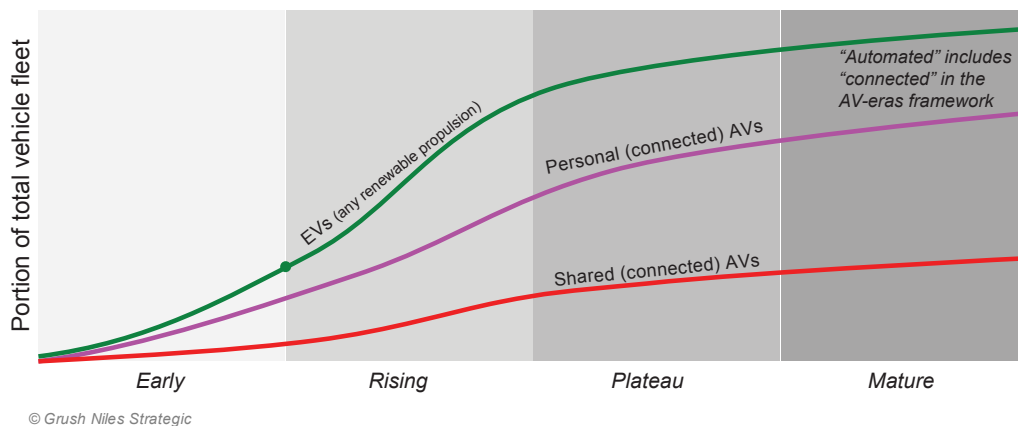
Hence, in this Part II, an alternative is proposed — a way for a regional transportation authority to move beyond an acquire-and-operate mode to one of specify-and-regulate. To do this, the final portion of this report develops a region-wide, cloud-based, multi-fleet harmonization system that relies on a new level of digital oversight that, in turn, leverages the systems that manage fleets of automated vehicles. Rudimentary versions of these fleet management systems are already in place and will mature as automated fleets are realized. The harmonization approach relies on distributing performance-based subsidies and road taxes based on big-data and open markets. This new approach is predominantly a “software” approach.

2.3 Automated Vehicles Will Diffuse Over a Number of Distinct “Diffusion Eras”

This report relies on a temporal framework within which to forecast a sequence of expected disruptions and changes in some relative order but without naming specific dates. Consider four consecutive eras that would last approximately eight to 15 years each. For economy of thought, these can be roughly considered as the 2020s, 2030s, 2040s, and 2050s — approximately a decade each.

Figure 1: Fleet Shift — Technology

Key innovations will diffuse through passenger vehicle fleets at different rates during four eras. Vehicles are likely to be equipped with alternative power trains slightly faster than they are automated (level 3 and above), and more automated vehicles will be personally owned than will be dedicated to shared service.



Taking automotive innovators at their word, we can expect by about 2020 both Level 3 (conditionally automated vehicles that require a responsible driver to be in the vehicle) and level 4 (highly automated vehicles to be constrained to certain areas and speeds and that do not require an onboard driver but would be remotely monitored as robo-taxis).

The four critical innovation components of new mobility expected to diffuse during these eras are collectively known as ACES: automated, connected, electric and shared. To simplify the planning discussion, this report combines connectivity and autonomy and uses the single category, “automated,” to describe both. The report also sharply distinguishes personal automated vehicles from shared automated vehicles, since each has dramatically different meanings for planning, infrastructure and urban livability, even if the underlying technology is similar.

Figure 2: Fleet Shift — Driving

As automation diffuses, semi-automated vehicles (partially and conditionally automated — level 2 and 3) will dominate the fleet before fully automated ones do. This means that in the Early and Rising eras, personally owned automated vehicles will dominate. This will sustain current traffic, parking and sprawl issues, likely making them worse.

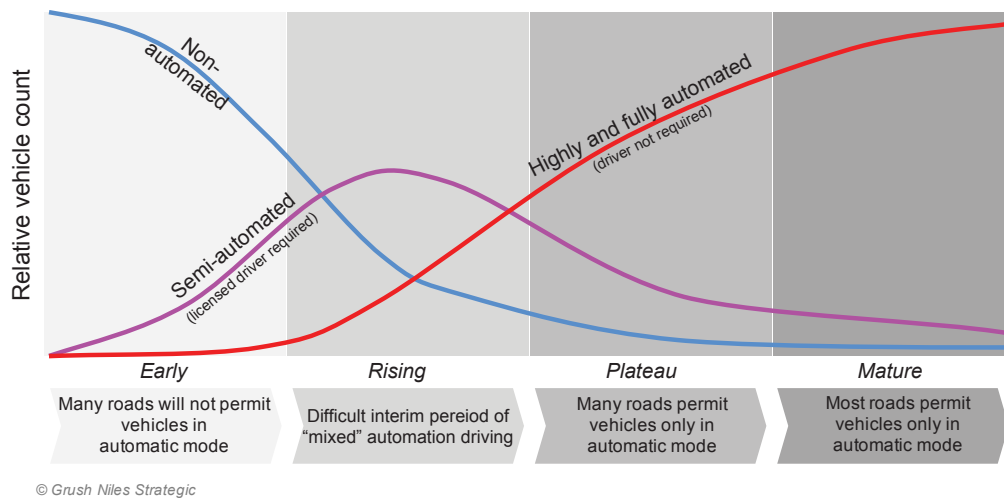
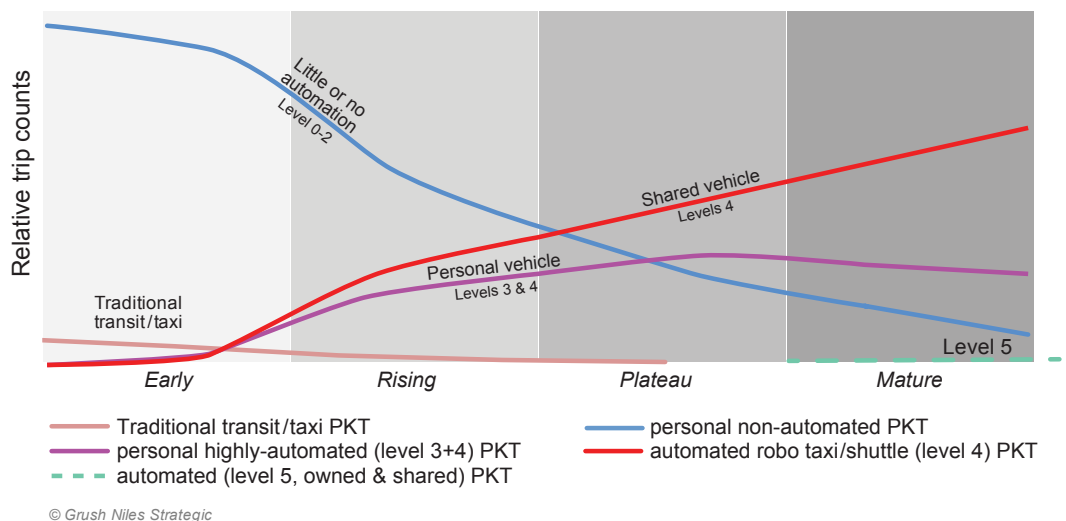


Figure 3: Fleet Shift — Mobility Choice

The trend of trip counts will continue upwards — demand will not shrink in the GTHA, because population will increase at 100,000 per year. Personally automated vehicles can be expected to play a substantial role in the third era, even as forecasts often claim that shared-service vehicles will dominate. This will depend on the level of “comfortable, affordable, fast and instantly available” (CAFI) services provided, and perhaps planning and incentives can shorten trips and promote sharing to accelerate the desired trends in the Plateau and Mature eras.



2.4 About AV Diffusion Eras in This Report

Dividing any innovation trajectory into diffusion eras is stock-in-trade for modelling how the relevant innovation can be expected to diffuse. The most familiar innovation adoption stages are known as innovators, early adopters, early majority, late majority and laggards. [Rogers]

The notion of eras used in Figure 1 to Figure 3 has a similar structure to the Rogers' adoption stages but it represents more. It is a super-structure that will inevitably subsume numerous innovations each with their own adoption stages.

Adoption of AVs by consumers or businesses cannot proceed on their own accord, as was the case for kitchen microwaves or smartwatches. Each of the AV diffusion eras involve technology, regulations, infrastructure, funding, integration with existing systems, and social change (or resistance) — each of which will have its own multiplicity of diffusion cycles. Those contextual diffusion cycles will be unleashed by automation technologies, but these will in turn overwhelmingly guide the pace and direction of the maturing new mobility. As an input, vehicle automation is an enabler — merely an input — but the output is vehicle sharing which arises as an emergent property.

It is everything in between that matters to planners.

We can understand the rough direction and changes to expect, which changes will have to occur before others, and that some jurisdictions will proceed more quickly or differently than others. Awareness of the forces of change and interdependence among those forces tells us why long-range planning will be difficult and why such a myriad of utopian and dystopian forecasts have credence.

Figure 4 on page 20, is a representation of the four eras of AV diffusion, guided by the core measure of the portion of trips taken in shared vehicles (top row). This is the key driver for planning land use, density, parking infrastructure, rail systems and many other infrastructural elements that are buffeted by high volumes of private vehicles.





There are reasons to imagine that this will proceed faster or slower than many forecasts suggest. But there is no evidence that we will reach 75 per cent PKT in shared vehicles as soon as 2050, if ever. This report argues that this will be very difficult but there is hope that this is achievable, and it describes infrastructural ways to bias change in that direction.

The system and user effects to be expected in each era are less certain as we move to later eras. For example, 3D printing coupled with Moore's law, new materials, advances in AI and energy capture and storage could make a personal, one-person vehicle safe, reliable and cost little more than a smartphone long before we reach 50 per cent PKT in shared vehicles.⁶ On the other hand, the social, economic and time value of mobility-on-demand may be so high as to make owning a vehicle a handicap without merit. This would drive shared vehicle use higher and faster. This report does not forecast either extreme. Rather it assumes the desire for private ownership will be hard to extinguish and systems to make vehicle sharing work for nearly every consumer of mobility will be hard to create and maintain. In spite of this, a way to do so is proposed.

The last three rows of Figure 4 summarize the expected fleet sizes and staff counts for robo-taxi and micro-transit provided by a GTHA model that assumes aggregate shared-vehicle targets are achieved in each respective era. The reader should assume these are rough estimates created in order to advance scenarios.

Figure 4: Shared Vehicle Progression and Diffusion

An aggregation of the kinds of transportation, traffic and sharing system changes forecasted as AV systems mature through four eras of adoption. Segmenting these eras with decade labels may be misleading (see text).

	Automation start	Shared vehicle progression and diffusion		
New mobility	2020s? Early	2030s? Rising	2040s? Plateau	2050s-2070s? Mature
	 10% PKT in shared vehicles	 25% PKT in shared vehicles	 50% PKT in shared vehicles	 75% PKT in shared vehicles
	<ul style="list-style-type: none">• Transit, carshare• Taxi, ride-hail, limo• 2017 services levels• Low volume robo-taxis• Some ridesharing• Some areas = no self-drive	<ul style="list-style-type: none">• Slow, short trips• Selective coverage• Single (O-D) trip• More ride sharing• Modest service level• ACES: automated, connected, electric, shared	<ul style="list-style-type: none">• Faster• Longer trips• Trip chaining• Majority coverage• High service level• CAFI: convenient, available, fast, instantly available	<ul style="list-style-type: none">• Posted speeds• Any length trip• Near-complete coverage• Extraordinary service• Extreme reliability• Demands CAFI
	<ul style="list-style-type: none">• Captive transit passengers• Unlicensed travellers• Transit deserts• Self-selected for ACES PKT	<ul style="list-style-type: none">• Captive passengers• Replaces 2nd car• A minority of divers move to no-car	<ul style="list-style-type: none">• Many drivers switch to no-cars	<ul style="list-style-type: none">• Majority of drivers move to no-car• Some areas = no driving
GTHA	Pop. 7.5M	8.5M	9.5M	10.5M
	Fleet Transit,Taxi,TNC	150,000	335,000	555,000
	FTE Transit,Taxi,TNC	30,000	67,000M	105,000

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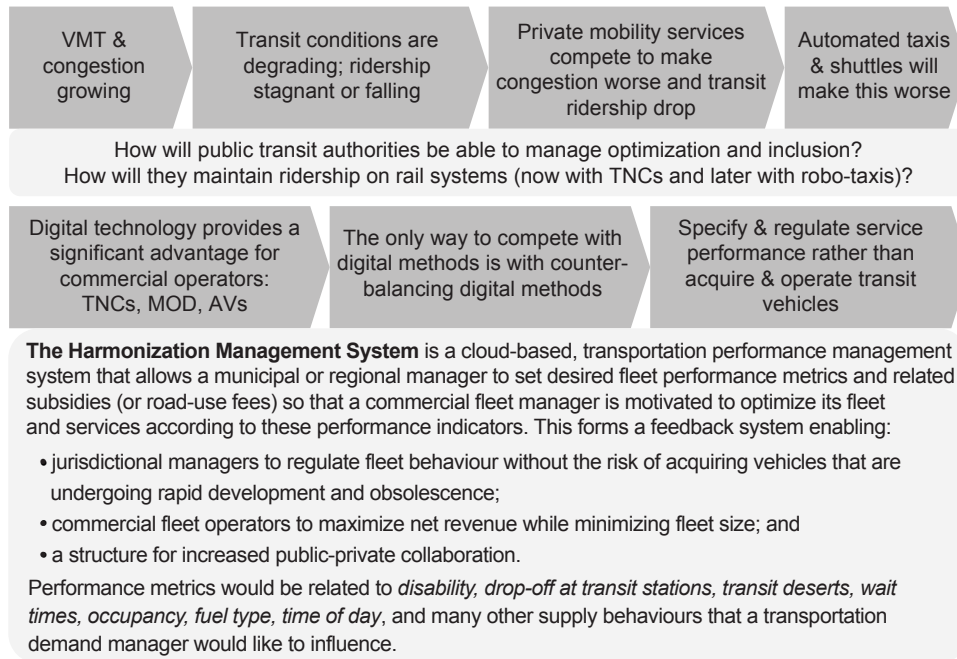
2.5 The Rapid Digitization that Will Cause the Disruption Also Points to a Solution

This report ends with the description of a performance-based, data driven system for harmonizing multiple competing fleets of shared-service vehicles. Fleet behaviour can be shaped by prices and subsidies to move both provision and consumption of mobility (trips) in the demand management direction desired by regional transit agencies as technology, planning and society change together.

The types of AI-reliant digital systems that now disrupt retail, news, music and taxis can be used to disrupt vehicle ownership and encourage or foster mobility-on-demand. For the new mobility described in this report, the potential to shape demand with feedback loops that take seconds instead of decades offers previously unimagined flexibility (Figure 10). This can provide tools to boost fleet service levels and traveller satisfaction, data for transportation managers, and direction for urban planners to begin the process of change needed to meet the subsequent eras of new mobility (Figure 5).

Figure 5: Harmonization Management System

The prevailing and emerging conditions (top row) can be addressed with digital tools (middle row) incorporating a subsidy and pricing system that produces the results described (bottom segment).



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3.0 THE BROAD CONTEXT OF CHANGE



The shape of new mobility is slowly becoming evident, enabled by automation, vehicle connectivity, smartphones, telecommunications and the cloud. Together, these provide the missing ingredients for a greater degree of optimization and inclusion for regional transportation systems. There are ways to regulate, deploy and manage this new mobility to ensure such an outcome. That it makes sense to do so may appear self-evident: Who does not want to reduce the congestion, financial burden, and environmental costs of today's surface movement of people and goods? Who does not want to improve access, availability and livability?

But obvious desirability is not a guaranteed outcome, just as introducing the automobile 120 years ago did not, in the end, resolve the horse-congestion problem. Whether we will do it better this time becomes the critical question. Beyond a possibly agreed description of a transportation or livability goal, the priority settings of planners and decision-makers are not in sufficient alignment to identify an agreed path to a goal. If such a path were to be agreed upon, it is not clear that we could afford it. And saying: "we can't afford not to" is unproductive.

Worse, there is typically even less alignment between the immediate personal preferences of travellers and the biddings of transportation planners. How often have we been told that 40 cars take up more road space than one bus? Or that electric vehicles reduce emissions? Or that ride sharing reduces congestion? How many motorists still rail against cyclists? People are slow to change to things uncomfortable, unfamiliar or that they feel take too much time.

Many travellers are non-responsive to attempts to have them reconsider modalities, so how will they respond to what is billed as the largest disruption to automobility since the arrival

of the automobile? There is considerable hope that the cost and capability of robo-fleets of automated vehicles will be so transformative that travellers will respond in the vast majority to the opportunity to no longer own personal vehicles. But given the human preference to maximize personal or family welfare and convenience over societal or environmental effects, this hope can be dashed very easily.⁷

Now, at the dawn of commercially viable, automated vehicles, there may be only one thing of which we can be certain: vehicle automation can't be stopped. Many thousands of person-years' engineering efforts, millions of test miles and tens of billions of dollars [Kerry] have been invested in the past decade. Some of the harder technical issues may still be unsolved — perhaps we are only half-way to that vaunted place of fully and reliably automated vehicles — but both commercial and safety value is already evident and growing in semi-automation and will start showing meaningful returns from full automation of constrained-location taxi applications in the 2020s. Commercial and social value is far too massive for cities to shun this technology, like some that have tried to sidestep Uber. The whole direction of both the traditional automobile industry and shared mobility advocates are now tilted toward reaching extreme automation. Furthermore, human driving is increasingly demonized as faulty and distracted. The road fatality rate in North America has started to climb after decades of decline, [Stav] and the long decline in EU road deaths has come to a standstill. [Eurostat]⁸

The journey toward vehicle automation cannot be halted, nor should it be.

With the first ride-hailing apps barely a decade old, we have entered the era of mobility digitization. It took Uber six years to reach its billionth ride and six months to reach its second billion. [Tepper] What digital technologies have done for music, print, broadcast, hotels, entertainment and hundreds of other aspects of human social and commercial activity has started to happen to automobiles, trucks and transit. This will now influence and be influenced by urban and transportation infrastructure planners. But there are a number of important uncertainties that need attention before the first fully automated vehicles hit the streets in Ontario's cities.

3.1 We Focus on the Wrong Issues

With the exception of a compelling and appropriate focus on reducing fatalities, we attend to most aspects of vehicle automation in reverse order of their importance. The largest portion of media print and almost all video is spent on the excitement of “no hands” — which is essentially early marketing for the next generation of personal vehicles. Of course, “no-hands” is critical to reducing fatalities, but it is described and viewed through the lens of trip convenience and an interest in repurposing human attention that can now be spent on other tasks. In a couple of decades, driving without a steering wheel will seem no more remarkable than driving a carriage without a horse.

Yet many significant issues — such as the likelihood of an increase in sprawl, [CityMobil2; Elpern-Waxman] the complexity of the interim mixed-vehicle traffic, and the risk to social equity as commercial fleets displace public transit systems [Ch. 3.10] — has been discussed far less often in the main-stream media, although this appears to be changing. Unfortunately, these

latter issues are only recently attracting the attention of planners and politicians, while the time required for the resolution of most of these issues generally extend beyond the current mandate of nearly all elected leaders.

3.2 Automation is Only a Catalyst

While smartphone, tablets, telecommunications, security systems and the real-time cloud infrastructure are critical enablers in the online, always-connected world, the real game changers are shopping, payment and messaging apps, Twitter, Facebook, games — the entire spectrum of mobile apps. [Friedman] The same will be true for automated vehicles. In addition to the foundational technologies such as sensors and AI, the world of mobility in 2040 will owe as much to materials, additive manufacturing, batteries, energy generation and storage technologies, security, and telecommunications as to vision systems and AI. But the real game changers will be what these vehicles are used for. How will they be deployed and used? Will fleets be optimized and shared? Just as the social effects of the smartphone now far outweigh its constituent and contextual technologies, so the social effects of the coming world of digitized mobility — which we are not likely able to fully anticipate, will far overshadow the details of the emerging technology. This should not surprise us. After all, the associated social and environmental effects of the 20th-century automobile were orders of magnitude more important than the vehicle innovations themselves.

3.3 Infrastructure: More, Less or Different?

For the past several decades the funding and construction of transportation infrastructure has increasingly lagged demand in Ontario and throughout North America. Whether that is because of a lack of funding, policies that assume we cannot build our way out of congestion, or policies that prefer public transit, is immaterial. What matters is that automated vehicles will increase vehicle kilometres travelled (VKT) and congestion into the mid 2030s or beyond. [Grush 2016] Can planners and their political masters defend coherent arguments about what to build and what to wait for in the meantime?

The 2016 RCCAO “Megatrends” study [Fenn] suggests that infrastructure will be increasingly flexible, adaptable, use new cheaper materials, and may have a shorter life expectancy, in order to avoid the risks of long-term, sunk costs against an uncertain future of new trends and new technologies.

Remedies such as scalable designs or less-permanent construction will be debated, but will planners start planning less or different infrastructure? It will be hard to argue for less future road or rail infrastructure to a voter population that still experiences or perceives sustained or even growing congestion. Even building rail, which could dovetail nicely with planning for robo-fleets serving rail stations, will be seen increasingly as a risk. But not building rail could mean more people eventually use personal AVs as single occupant vehicles (SOVs), which would almost certainly generate more road volume and congestion.

3.4 How Long Should We Wait Before Acting?

Many observers criticize regional and municipal transportation plans for not including provisions for AVs. Until we understand the practical implications of AVs in our cities and regions, what can be included usefully in a transportation plan is hard to determine beyond a speculative and cautionary description of tentative technologies and a suggestion of what will need to be considered when deployment becomes more certain.

In March 2017, the Toronto Transit Commission (TTC) released a staff report saying it would wait for further AV technology maturity before taking any material steps to prepare for vehicle automation. This hesitation was due to a lack of clear execution steps and to the variability in the study team's perceptions of the expected advantages and risks of AVs.

“There are too many uncertainties in the capabilities of the (automation) technology, the cost, the restrictions, and the timing to be able to develop a TTC strategic plan or consider their implementation at anything further than a preliminary level.”

— Byford

The TTC report framed the advent of automated vehicles in two stages of equipment upgrade (first non-automated to semi-automated, and later semi-automated to fully automated) with expected service improvements at each stage. But it is far more likely that vehicle automation will cause a total transformation of the movement of both people and goods rather than two rounds of improvements to the current fleet configuration. Although it was not considered in the report, officials need to recognize that transit systems — especially bus transit — could be disrupted severely with a new vehicle size mix around the same time-period that a bus system such as the TTC's would be in mid-upgrade. [Ch. 3.10]

In other words, upgrading current bus transit to operate without drivers would risk a massive, wasted investment for the TTC — unless we could predict something reliable about the diffusion of robotic vehicles — which we cannot. Although the TTC is right to hesitate to recommend an investment, the agency still must anticipate and prepare.

This same observation applies to planning physical infrastructure. Unless we understand how we will design, own and use automated vehicles, there is no bankable answer to the question “what infrastructure should we build?” Given a sustained or growing demand for passenger kilometres per capita, the current Ontario or North American circumstance of 700 or 800 motor vehicles per 1,000 population is dramatically different from a world of 100 or 150 vehicles per 1,000 which is what is being contemplated by those hoping no one will own a vehicle. This can change everything about infrastructure planning. If one gave these two extreme examples to two independent sets of planners, one would get wildly different future outcomes for the GTHA.

So, while you might cringe if an elected official or key decision-maker says, “let's wait and see,” you should cringe even more if the same person were to say, in 2017, “we know exactly what to build.”

3.5 Social Change Will Dwarf the Direct Effects of Automotive Innovations

The total spectrum of social change from new mobility will be far greater than such things as the traffic changes due to narrower lane widths, shorter headways, optimized intersections, and reduced parking demand. Many jobs — including spin-off jobs related to driving — will change, and some will drop in number, although there will be many new jobs that few people talk about. [Table 1] In addition to unknown social equity effects — things could improve or worsen for lower-income travellers — there may be negative health effects from an increased degree of sedentary travel, [Schwartz] positive health and family effects from fewer injuries and fatalities for some, negative life-span effects due to a drop in the availability of organ donors for others, or health-effects related to more walking and biking if parking and lanes are re-purposed for livable communities and robo-taxis have drop fees that discourage overuse for walkable trips. Out-migration patterns shift municipal tax bases — residential property taxes are affixed to where you sleep as opposed to where you work, and this may disproportionately impact the central city in the region of a cluster of towns — specifically Toronto and the GTHA's 25 other municipalities, many of which have more affordable — and for some, more desirable — housing.

The number of secondary and tertiary ripple effects is unlikely to have been fully enumerated and the ones that have been called out are not necessarily well understood. One of the largest effects will be the end of municipal bus transit as a large-vehicle, fixed-schedule, fixed-route, and constrained-supply service. [Ch. 3.10] This will cause some cities to eschew ownership of public transit infrastructure in favour of subsidizing TNC operators, as was recently demonstrated by the Town of Innisfil, Ont. [Pelley] Other transit agencies will incorporate new technology and new on-demand service models to preserve their role in a shift to more flexible and less costly transportation-as-a-service models. The difficulty for both decision paths will be the interim decade or two as the shift to more automation settles in.

3.6 Two Markets

A focus on gradual feature improvements in automotive intelligence puts us off the scent of the impending dual diffusion process. [Ch. 4] Not only will vehicle automation technology diffuse to disrupt the personal, non-automated vehicle market, but it will also, in its robo-taxi format, diffuse to disrupt the ride-hiring market, e.g., taxis and urban bus systems. These two formats — personal household vehicle and public access vehicle — will compete against each other. Indeed, that public-transit robo-taxi fleets would compete with commercial-public fleets is a critical concern. [UITP] This two-way or three-way diffusion and competition will complicate the infrastructure planning decision process and dilute its potential, positive outcomes. Competition will minimize collaboration, which will reduce the opportunity to optimize the full mobility network while perpetuating the demand for redundant infrastructure. In a world that may need **resilient infrastructure** more than redundant infrastructure, much of the value of vehicle automation may be squandered as it worsens the experience of accessing the infrastructure we currently have.

Indeed, the notion of dual diffusion is not new. There have always been two markets for mobility: the ownership of a private conveyance vs. the hire of a provisioned ride. In the 20th century, this was private car vs. transit and taxi. Consider that cars, trucks, buses, taxis, bikes and pedestrians now compete for space on existing infrastructure. Consider the friction already evident in that system. Now add semi-automated and fully automated cars and trucks on our streets, automated delivery carts on our sidewalks, and finally begin to imagine how the current rivalry between personal and public vehicles could be exacerbated by the arrival of a variety of automated vehicles.

The regulation of for-hire vehicles stretches back at least to the 1650s in the form of hackney carriages and certainly people hired rides long before that. The portion of any population that owns a private conveyance vs. hired rides has always varied over time, place and wealth. The fact of variation likely will never change, and the assumption that a technology-enabler alone is enough to eradicate this multifaceted-interplay is naïve. The assumption that person-travel in 2050 will be predominately satisfied by fleets of shared vehicles, however attractive, is without a guaranteed path to realization in spite of its evident enablers. Nonetheless, its attractiveness is the single largest motivation for this report and its predecessor and the basis of the proposed approach to automated fleet harmonization. [Ch. 6 and 7]

3.7 The Installed Base Matters

Slowing down all this change is a massive installed base. Roads that were built for cars and trucks, which were previously dimensioned for horses, or in some cases for donkeys and pedestrians, and often under repair, [Marshall, A.] make the job of automating driving much harder in many cities than would be the case for roads designed and built with automated vehicles in mind. This means that open roads suitable for switching personal vehicles into self-driving mode will initially be far easier to automate than would be city streets expecting fully automated robo-taxis. Hwy. 407 will be easier to prepare than would Queen Street, and the U.S. I-95 easier than Manhattan's streets.

There is an even more deeply embedded installed base that must be considered: people like to make immediate trip decisions and many have more complex personal preferences for their chosen modality. [Ch. 5] In that environment, it may seem impossible to design and manage public fleets that will satisfy nearly all demands. While 25 per cent of all motorized person-travel in a robo-taxi is easy to imagine, 50 per cent is a little harder to imagine. Arguing for 80 or 95 per cent is very challenging, but that is what is being forecasted in some quarters. [Corwin; Arbib]

Automating individual vehicles will be hard enough, but to automate and optimize fleet behaviour so that “no one needs to own a vehicle” will be much more challenging. And while vehicles may become fully automated, they will never be truly autonomous — they will always be at the command of people with specific and arbitrary needs, overseen and guided by whatever gradually diminishing human oversight is required, and under the constraints of whatever system optimizations may be permitted.¹⁰ This fact alone demands a complete undertaking in

regards to a new world of regulations for both private and public fleets — everything from highway traffic regulations, taxi policies, municipal transit planning, road construction, road funding, security, safety and privacy. [Eno]

3.8 Urban Transportation Challenges Will Get Worse Before There are Improvements

The semi-automated household vehicle market will grow much faster than the robo-taxi market. This differential will be for technical, infrastructural and human preference reasons. The semi-automated vehicle under private ownership will result in more outward growth, cause more congestion and demand more parking until the robo-taxi market is able to catch up and possibly halt or reverse the process. [Grush 2016]

Change is almost always difficult whether for individuals, cities or countries. Even more so for big changes. There is no obvious path from the complex, multi-dimensional, every-driver-for-himself, and costly way we currently deploy and manage cars, taxis and transit now to a proposed state where we would deploy and manage automated cars, taxis and transit in a new and presumably better way. As we fumble partially blind toward the path we will take, there will be faults, false starts, and surprises. Furthermore, there is no guarantee it will be what we had hoped for when we arrive at a new end state or that we would even recognize it if we arrived. [Grush 2016, p. 31] For this reason, proposed solutions should be flexible, preferably in digital form rather than as a fleet acquisition or a new type of roadway. [Ch. 7]

3.9 Attention is the Prize

A central aspect of being human is that one of our most constrained resources is immediate personal attention — day by day, hour by hour and minute by minute. We always seem able to find more energy, pack people into denser spaces or squeeze more nutrition out of a hectare. But how much a person can focus on while awake is a limited resource: when you hit your limit, you hit a wall. Due to this limit, the global value of tapping into people's attention span is always rising — something that is less true for innovation or creativity which seems to have fewer limitations. The harvesting and monetization of attention is the source of revenue for many industries such as television, Google, social media and telecommunications. [Wu] Without drawing upon human attention, advertising, education and communication would have little value.

Mostly this point is about consumption, even if only consumption of digital media and Internet bandwidth while travelling. The attention span of today's vehicle operators is a critical, non-renewable resource for safety; too little and you get road fatalities. How many of these fatalities are unintended payments to social media giants for a dopamine drip? A productivity assertion frequently made by enthusiasts for self-driving is that you can attend to something work related — giving over your attention to generating profit whether for yourself or someone else — or perhaps over to the Internet to be monetized by Google or a social app.

Effectively, vehicle automation monetizes trips by converting the driver's focus on moving safely in congestion into attention on something else. Longer drives and trips on transit systems will increase profits for all who engage in harvesting the new oil fields of attention from travellers. The ability for others to monetize your journey will be increased. Your daily [Marchetti] time budget will be farmed. If the automated vehicle will increase productivity, it will also increase the tax-base. Hence, government and corporate interest is unsurprising.

The frequently heard argument that the value of the data generated from your automated trip will exceed the cost of your trip speaks to attention; that data will be mined to search for more opportunities to monetize. That data can be about optimizing transportation or mobility, but in an even bigger way it will be about marketing. And without your attention, there is nothing to market to. The purveyors of the technology for new mobility don't really want you sleeping behind the wheel. They want you consuming behind the wheel.

It might be tempting to dismiss what travellers do when the driving task is removed as relatively unimportant compared to safety, congestion, sprawl and disruption of existing transportation systems. But understanding what is motivated in the new business models for provision of mobility is critical. The old mobility operators focus either on selling vehicles, vehicle accessories, fuel, insurance, financing, status and other monetizable elements of 20th-century automobility or they focus on selling seats on transit vehicles and concomitant social inclusion. The new mobility innovators that sell vehicles are able to monetize more — especially if they can capture your attention. More to the point, new mobility innovators able to sell rides rather than vehicles can compound monetizable value in ways never before considered. This factor, poorly understood and anticipated, will drive new ride-selling business models and services to the detriment of both traditional transit and car-sellers.

3.10 What Will Happen to Public Transit Systems?

The two pillars of public transit are **optimization** and **inclusion**. **Optimization** is principally addressed today with large, regularly scheduled, line haul buses and trains using trained, professional operators that move masses of people efficiently and safely. **Inclusion** is addressed by having these vehicles and routes planned in a way to offer city and regional mobility for urban residents throughout a service territory for at least a few times a day or sometimes a number of times each hour. As well, the vehicle movements of public transit are generally heavily subsidized and often incorporate accessibility programs to foster even greater inclusion.

The most socially equitable way to move large numbers of people and the currently preferred way for most individuals to make a personal trip are 180° different: public transit or automobile. This does not mean that every automobile trip is better for its passengers than is every public transit trip, but rather that a current majority prefer the former — and for a complex set of reasons. [Ch. 5]

The current interplay between public transit and motorized private transportation and hybrids such as taxis, ride-hailing and carshares is set in a complex social, economic, geographic, demographic, technological, historic and human behavioural matrix within which each traveller

holds a view. This would include the views of a planner or city-builder or that of a commuter or shopper in one of a large variety of personal and economic circumstances. Regardless of one's personal position about the public-transit-personal-vehicle spectrum — which is currently in considerable flux — most travellers make travel-modality decisions to suit their personal requirements and constraints. More often, they will choose something with a view to comfort, cost, speed and convenience within the immediate context of their trip. Hence, of all potential motorized modalities, the private car is the one most often selected.¹¹ From the individual traveller's perspective this is often rational. From the planner's perspective this is non-optimal and exclusive.

The arrival of automated vehicles will alter the decision criteria exercised by the individual traveller who in the whole will choose based on comfort, cost, speed and convenience — i.e., beyond the shadow cast by any current transit planner's preference. A cheap robo-taxi — the future of ride-hailing — will compete with bus, taxi, carshare and short-haul subway trips. The current 50-passenger city bus configured, sized and operated as a fixed-route, fixed-schedule system will not be able to compete with this new option as its cost plummets during the price wars of the mid-to-late 2020s as robo-taxi fleet operators jockey for market. The business target to be disrupted by the new mobility competition early in the automated-vehicle era will be the current business model of public transit.¹² We already have hints of this with ride-hailing services, negatively affecting transit ridership in a number of cities [Schaller; Clewlow] and substituting for bus routes in others. [Pelly]

Thinking about the disruption of bus transit by automated vehicles might be considered analogous to posters comparing the space occupied by a 50-person bus vs. that by 50 single-occupant vehicles. There are at least two problems with this comparison.¹³ The first is that 50-person buses are fully occupied only during peak hours and on some routes, while it takes 33 cars, not 50, to carry 50 people at 1.5 occupancy. The second problem is that many future vehicles that will play a public transit role would be six- or 12-person micro-transit vehicles with average occupancies likely closer to three or five. Additionally, well-coordinated, right-sized vehicles, whether carrying one person or ten, would be distributed very differently as each route would be optimized wherever possible for the origins and destinations of just those people in the vehicle. It is also the case that such vehicles *could* be organized to connect with light or heavy rail transit. [Ch. 7]

The *core* issue for the disruption to public transit will not be a matter of upgrading vehicles, flexing routes and conserving jobs as some transit authorities may suppose. [Byford] Rather it is to return to the foundational principles of optimization and inclusion, but now within a fully digitized mobility system that will be physically unrecognizable to current transit planners and operators. Even while there may be no significant role for the 50-person city bus in the 2030s, there would be a larger and more demanding role for public transit to achieve optimization and inclusion. [Ch. 6 and 7]

Despite that longer-term view, many transit agencies are likely to take a shorter view during the 2020s and consider automated micro-transit vehicles especially for first/last mile applications as has started in several cities. [Grush 2016, p, 45]. Non-automated public transit, small-bus

operations have a recent history of between five to ten percent of the total bus-transit population in North America, [Hemily] including perhaps half of that as paratransit. This documented experience will be useful to transit agencies where automated, small-bus systems may spread.

3.11 Job Change, Before Job Loss

Vehicle automation is generating a significant concern for potential job loss. Surely automation takes some jobs away. And it also creates others, with net job counts sometimes dropping. But the picture is not straightforward even in the case of transit systems with massive expenditures on driver wages. Some of the new jobs will be more complex and higher paid than a driving job, many could be lower paid — especially if the transit function shifts to the private sector. One of the best ways to retain job counts and job value is to ensure that transit self-disrupts and moves toward a program such as Transit Leap [Grush 2016] while growing ridership, retraining and retaining transit staff. There will be many new ways to experiment with improved suburban transit options as this technology develops. These are the opportunities that the TTC shunned when it decided it was not ready to experiment hands-on with AVs.

3.12 Human Behaviour and Behavioural Economics

All sustained human behaviours originate in our species' social, biological and cultural history. Art, religion, [Wilson] war, [Smith] preference to live in suburbs, [Kanazawa] and embrace of powered automobility [Grush 2014] are among them as much as all the forms and behaviours we are more accustomed to thinking of as evolutionary traits. Humans seem to have an average daily travel time budget or tolerance of about one hour. [Marchetti] Powered mobility increases the range that can be reached in that hour, which is a powerful reason for a personal vehicle often being preferred over transit, and why people are annoyed by congestion. We seem to have a long-standing budget of about 12 to 14 percent of our disposable income to spend on transportation. This explains why some people will buy larger vehicles with more powerful engines when CAFE standards raise fuel efficiencies.

The assumption that person-travel in 2050 will be predominately satisfied by fleets of shared vehicles, however attractive, is without a path to realization despite its evident enablers.

People also tend to have an appetite for risk taking, a modicum of which would have had evolutionary value. That preference sometimes shows up in the modern world with less evolutionary value: when seat belts first came in, some drove faster than they did before wearing seat belts became mandatory. We can also expect human perception of AV risk will morph with experience and we will see, more or less, acceptance depending on that experience. It can be expected that some will be especially cautious around automated vehicles, while others would behave more frivolously or carelessly.

While an economically rational response to the availability of a guaranteed, cheap, convenient, always reliable, robo-taxi service might be to sell the family vehicle; this outcome is far from guaranteed. [Ch. 5] Indeed, while some people may behave this way it is by no means certain this would happen quickly, nor that it would persuade a majority to do so. Sociobiological evolution demands flexible, personal, capable, immediate, and responsive mobility, [Grush, 2016] and this will make many of us cautious in any decision to give up our private vehicle.

We know that some people are willing to share rides, others are not. Varied preferences are also seen in the sharing of cars, whether personal or in response to a commercial service like Car2Go. The problem with these known human preferences is that we do not have a good handle on how they will affect human decision making when faced with buying cars, buying dedicated rides and buying shared rides. [Ch. 5] Specifically, we do not yet understand what level or types of service provision will be required and at what cost to attract car-buyers to become ride buyers. It will likely be very easy to persuade most current ride buyers to become robo-ride buyers. It might be almost as easy to have many families give up a third or second vehicle. But what will be needed to have families or individuals give up all vehicle ownership?

There is no evidence yet that sharing can be accomplished on a large scale, even as it becomes visible on a small scale. And until now there is no comprehensive plan to encourage this.

4.0 AN UNEASY TRANSITION: TWO COMPETING MARKETS

There have long been two fundamental choices for a person engaged in motorized travel: use a personally owned vehicle or a vehicle for which one pays to ride. For many of us in North America this means a personal household car, and all the other modes. The private car is, unfortunately, in a psychological class by itself, and this fact will be fundamental to the diffusion of automated vehicles.

Popular descriptions of the capabilities of automated vehicle technology rely on the concept of a single innovation trajectory improving in five linear stages until the driver is finally and absolutely redundant. [see Levels (SAE) in the Glossary] Taken as a diffusion roadmap, this is simplistic. The Society of Automotive Engineers (SAE) inadvertently promulgated this popular misconception of a singular, linear improvement in the marketplace for consumer vehicles when they sought to provide a simple descriptive scale by which to measure stages of technological progress.

But there is, after all, some validity to such a descriptive view — technology does move forward whether smoothly or in spurts, and we humans like to measure, distinguish, and categorize. But this SAE technical-progress harness obscures more than it reveals. The idea of a vehicle that needs no human oversight under any circumstance has led to a flood of imaginative scenarios about personal transportation over the next few decades. These scenarios typically lean toward views of the family car making personal travel wonderful again or a description of urban robo-taxis saving cities from the blight of traffic and parking. When these scenarios are described in isolation, they are predominantly utopian: “everyone of every ability from the age of 8 to 88 will be able to command a safe personal vehicle” or “no one anywhere will bother to own a vehicle given that you can demand the one you need and it will arrive in only two or three minutes.”

What is becoming more evident is that some of each of these will unfold concurrently, and diffusing only gradually, along with a lot of interim states of automation that are less frequently contemplated. This concurrence will lead to an atypical, dual-stream diffusion model for the coming markets for automobility: a market for buying cars and another for buying rides. Both will be significant, mutually competitive, and demanding of space, infrastructure, regulation, and investment. This fact makes the coming decades more difficult to divine, portends government indecision, and virtually guarantees massive inefficiencies, compared to the two extreme “utopias” on offer.

This chapter is not a recipe for avoidance of this two-stream competition, as it is unavoidable. Rather, the intention is to understand why the two streams are unavoidable and why our actions in the next two decades are crucial to a beneficial mid-century outcome.

4.1 Which View Illuminates the Disruption?

Indicative of the underlying nature of the consumerist view — as distinct from the transportation planners’ view — of the coming automated cars is that the exaggerated hype tells us we can soon

buy one and sleep on the way to work. A recent autoevolution.com article claimed: “... researchers from Morgan Stanley believe that automated vehicles would bring a boost of up to US\$98 billion to the alcohol industry ...” [Toma] In October 2016, a self-driving beer truck created some of the first buzz for automated goods movement by making a 200-kilometre delivery. One can see how this could pique the interests of consumers and journalists.

Of course, a social perspective cuts across the viewpoints of both consumer and planner. In the flood of papers and articles about vehicle automation there is a growing number of stories about concerns for liability, jobs, safety, congestion, the final destruction of the taxi industry — and now transit — by robo-cabs, and whether these robots would, in a bind, choose to sacrifice their passengers by running off a cliff to avoid hitting pedestrians or cyclists.

Just as the terms self-driving, semi-automated, driverless, fully-automated, and autonomous are applied indiscriminately, so too is the word “disruption.” Disruption describes what happens to business models, not technology. Technology is merely an enabler for a disruptive business model; how it is applied or consumed is what can make it disruptive. Vehicle automation could disrupt public transit if it reduces transit ridership, causing transit agencies to shrink routes, or lay off drivers. Such an effect can be triggered without automated vehicles as Uber and Lyft have already illustrated using drivers in non-automated (SAE level 1) vehicles. [Schaller; Clewlow] Reports have also illustrated that disruption effects cut both ways, allowing transit route reductions in some cases and increasing ridership in others. [Pelley] Now the impending introduction of constrained-area robo taxis by Uber and NuTonomy [Robarts] will soon bring SAE level 4 vehicles to bear on transit ridership. Then what?

There is indeed potential for disruption of a business model that demands a public transit agency reach as far into its peripheral urban limits as subsidies permit in the name of social inclusion, or under the banner of travel demand reduction by trying to blunt the onslaught of single occupant vehicles into the city centre.

But there is a wider municipal activity model under threat as well: municipal transportation management. As mobility digitization [Grush 2016] grows more competent, innovative and pervasive, demand for infrastructure change will occur — the amount, its configuration, and its oversight. This includes parking, lanes, speeds, congestion, transit (vehicles and routes), and enforcement. Just consider what distracted driving from texting has already done for safety, enforcement, and congestion.

To consider the market diffusion of automated vehicles as a single stream of innovation in same the way one might study the diffusion of the original automobile, microwave oven, TV or cell phone is not useful. The reason is that while the idealized automated vehicle springs from a coherent body of AI, sensor and mapping technology, there are two distinct motivating consumer models — two separate markets — for the actual automated vehicle. And each has its own diffusion path.

4.2 Two Consumer Markets

As mentioned above, business models are what's disrupted, and the automated vehicle is disruptive of two: (1) household ownership of vehicles and (2) publicly accessible shared use vehicles — i.e., the businesses of selling cars or selling rides, respectively.¹⁴ Both business models already exist and they already compete for users and infrastructure. Worse, aspects of the automated vehicle technology favour each business model differentially and are sometimes diametrically opposed. In what way will their related markets change due to the diffusion of vehicle automation into both markets? To say, "Transit will be disrupted by vehicle automation" is unrevealing. Which kind of automated vehicles? What sort of disruption? Will transit fade toward zero, come to dominate, or remain at its current single-digit contribution in North America of about 8% of PKT?

Consider that the existing competition between car selling and ride selling has a place for carmakers on both sides of the competition. This new competition means more ride selling in two- to 12-person vehicles rather than in buses, which in turn means that the opportunities for carmakers to win more market will expand. The deck will remain stacked in favour of car making.

If we knew which consumption model — cars or rides — will dominate, it would be easy to describe the nature of the coming disruption(s). Robin Chase famously summarized this problem in her 2014 Heaven-or-Hell article. [Chase] But choosing to describe only two extremes — mostly owned or mostly shared — is rhetorical and is a bit like describing the outcome of a single round of Russian Roulette with all chambers full versus all chambers empty.

The economic position of the automotive industry will strengthen regardless of whether travellers prefer buying cars or trips. Certainly, vehicle designs will be altered, how profits are made will differ, and the nature of jobs will change, but cities and communities win in every way if travellers prefer to buy trips. The trick will be to do what needs to be done to shift car-buyers' preferences toward ride buying.

To determine whether we are embarking on a journey to Heaven or to Hell, let's look at the forces at play for the diffusion of automated vehicles. After that we can leave the final exercise of choosing the principal direction to industry and government, because — as we know — the typical citizen will choose the path of personal preference or convenience, whether it leads the commons toward Heaven or toward Hell.

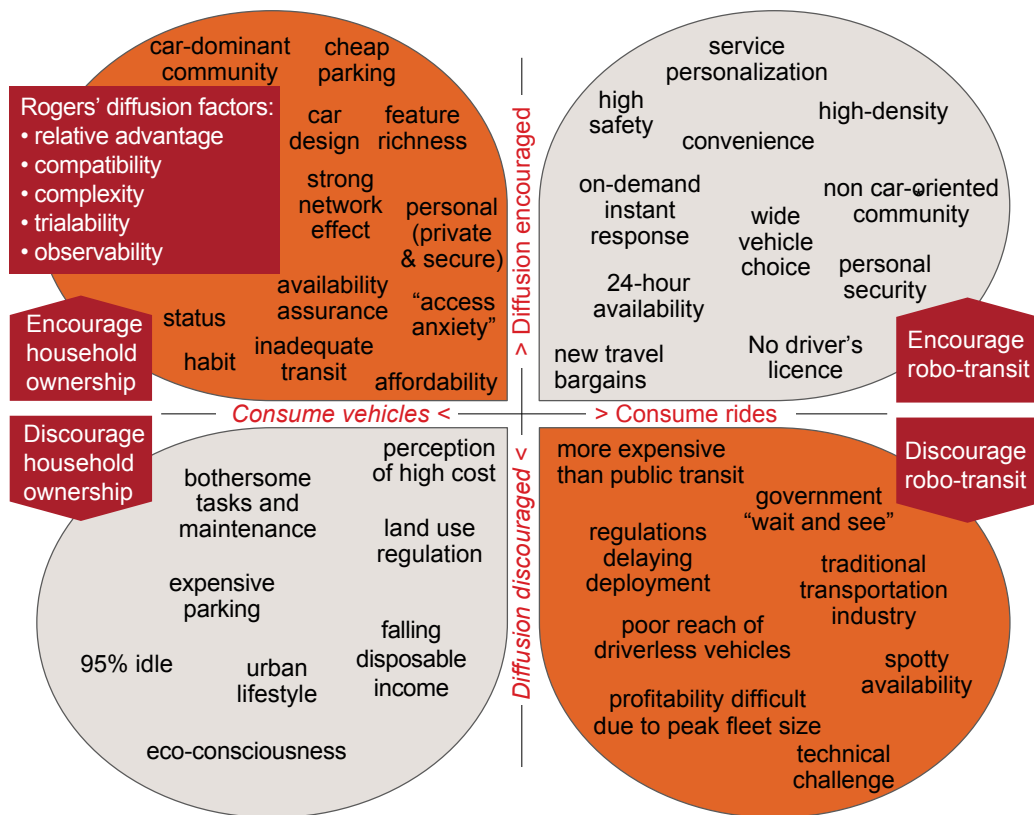
In Figure 6, the automated vehicle consumption market is divided into two simple halves: selling vehicles (left) and selling rides (right). Of course, selling rides means that someone still sells vehicles, so that making and selling vehicles does not go away; rather, it grows due to faster relative turnover, and increasing VKT — which is how the automotive industry gets a win-win hand. Any jurisdiction, such as Ontario, seeking to save its incumbent automotive manufacturing market should be focused on manufacturing for both markets. But if such a jurisdiction wants to optimize mobility and ensure mobility inclusion, it should lean a little more toward the ride-buying market — win-win.

The market forces of diffusion are also divided in a simple binary fashion as they might influence for or against the consumption of cars (top left, lower right) versus rides (top right, lower left). Such a simple dichotomy may miss nuances and some of the markers falling on one side or the other may be equivocal, but the figure acts as a starter map to the landmarks along our way to Chase's driverless Heaven or driverless Hell.

The next four sections examine Figure 6 clockwise from the upper left.

Figure 6: Consume Vehicles or Consume Rides

The upper left quadrant maps factors that encourage personal vehicle ownership. The lower-left maps factors that discourage personal vehicle ownership. The upper right quadrant maps factors that encourage the adoption of robo-vehicle rides. The lower-right quadrant maps factors that discourage the adoption of robo-vehicle rides.



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4.2.1 Forces Expanding Diffusion of Vehicle Ownership (upper left quadrant)

A good starting place when thinking about the diffusion of the automated vehicle is Everett Rogers' list of "diffusion factors" from his classic *Diffusion of Innovations*. [Rogers] By the early 2020s for most people and most trips in North America, a personally owned, semi-automated household vehicle would hold a real or perceived **relative advantage** over alternatives — especially over the alternative of not owning a personal vehicle. Owning a household vehicle is largely **compatible** with current infrastructure, social values, habits and travel preferences. Its use, for those who will afford it, will be on average **less complex** than carsharing or transit as they are currently configured — assuming those options are even sensibly available for persons in this thought experiment. By 2020, the **trialability** of a semi-automated (Level 3) vehicle can be expected to be higher than that for riding in a fully automated (Level 4) vehicle, and thus it will be commonly **observable**.

The last two of Rogers' factors, trialability and observability, may show a smaller and eventually vanishing differential between ownership and ride-buying a few years after 2020, as robo-taxis and robo-shuttles become available for use, but Rogers' five diffusion factors are selective for ownership now with important reinforcement of pre-2020 user perceptions and fears. Asking people their consumption preferences in 2017 may be as useful as asking a horse-and-buggy owner in 1889 about his preference for switching to a Stanley Steamer.

In addition to the current weight of Rogers' core diffusion factors, there are other ownership-favouring forces at play for automated vehicles. Habit, status, privacy, security and the sense of assurance we get from "my car" all promote the compatibility of ownership of a semi-automated vehicle for a majority of current vehicle owners. Unless something causes such people to reconsider their preferences in the light of alternative transportation services that are indeed more personally desirable they would, by default, elect to own a semi-automated vehicle rather than consume rides from a robo-vehicle service.

"Even though every innovation is judged on economic grounds, at least to some degree ... every innovation also has at least some degree of status conferral. Overadoption is one result of the prestige-conferring aspects of adopting an innovation. Overadoption is the adoption of an innovation by an individual when experts feel that he or she should reject."

— Everett Rogers, *Diffusion of Innovations*, page 231

Rogers' insight about status is important as we consider assertions from some experts claiming that many or most people will largely abandon ownership in the face of vehicle automation:

In this dual diffusion situation, of course, status conferral might cut both ways. In 2028, the status value of travelling in a high-service Level 4, region-spanning, robo taxi might carry a different contextual meaning compared to that of owning a 2023 Level 3 Tesla.

There is also something we call “access anxiety” — the rational concern that a vehicle may not always be able to negotiate every possible travel circumstance the owner requires. [Grush 2016, p.28] This will be reason enough for most to own a semi-automated vehicle until the reach of the fully automated vehicle (owned or not) handles the great majority of all trips. Access anxiety will operate for the first decade or two for the fully automated vehicle in the same way range anxiety still is a factor for the electric vehicle whose sales failed to skyrocket starting in 2010, as promised a few years earlier.

Another force to make owning a vehicle, including a semi-automated vehicle, attractive is the sheer power of automotive design and marketing — its delicious “feature creep.” My eyes puddle with desire as I sit through the false promises of open-road car ads in front of every movie — my desire for a new car undampened by ads for new bus routes or a car-sharing scheme. Consumer desire and concomitant overadoption are bound up in numerous, powerful behavioural-economic forces that are not easily rationalized away. Automotive marketers have mastered this socio-biological space.

Add to this that most of the developed world is fully configured with the necessary network to support vehicle ownership: the installed base of roads, plentiful locations to buy cheap fuel, sales and maintenance depots, whole dedicated sections of newspapers, endless advertising, and low-cost or free parking in uncountable circumstances.

For the automated vehicles Silicon Valley and Detroit are scrambling to offer in the early 2020s, there await daunting forces saying “buy me!” to a majority of people and families in the developed world that are accustomed to owning personal or family vehicles. As automated vehicles become affordable, then-current car owners will adopt semi-automated, self-driving, SAE Level 3 vehicles. A fully automated (SAE level 4) vehicle will not be practical to own due to access anxiety, and a Level 5 vehicle will not be practical to make universally available in the next few decades. Given current social and conurbation structures, only a small group of then-current owners will choose to adopt non-ownership in the 2020s (upper right quadrant).

The forces in the upper left quadrant are largely outside the reach of policy and planning. These are strong and culturally embedded. Some have become almost unconscious. [Thaler] People won’t easily be nudged out of this quadrant, which has forces that are unlikely to diminish significantly during the 2020s. Only manipulating the factors in the other three quadrants would draw consumers more reliably from the upper left to the upper right. In other words, we will experience little success pushing owners away from ownership, but we might have some success pulling them toward non-ownership (Chases’ Heaven). Perhaps we can help young non-owners remain non-owners even as they begin families (although that may be more difficult). This may sound equivocal, but from a behavioural economics perspective, [Samson] it is not.

4.2.2 Forces Expanding Diffusion Of Vehicle Ridership (upper right quadrant)

Some people will find reasons to stop owning a vehicle in the 2020s. These are people moving toward lifestyles that increasingly indicate less ownership (retirement, telework, moving close to work or to a non-car community), especially in conjunction with the sparse, but growing number of alternatives, including newly emerging MaaS services. [Hietanen] The growing inconvenience of car ownership, parking and driving will push some to abandon the 20th century freedom of car ownership in favour of the 21st century freedom of non-ownership — **should that alternative be reliably available.**

Any factor that increases the relative, perceived value of alternatives weakens car consumers' bonds to ownership. These factors might be few and less evident in the 2020s, but as they grow, they threaten the attachment factors in the upper left quadrant. Principal among these would be high transportation service-levels including low price, numerous choices, user convenience, high availability and responsiveness, personal security and privacy, as well as service personalization.

As the forces in the upper right quadrant strengthen, current owners will be pulled toward non-ownership. An example might be a car-owning retiree moving into a walkable community that has robo-taxis for local shopping, dining and entertainment and robo-shuttles to transit trunk lines. But a switch to non-ownership would be nixed if their grandchildren live in the suburbs an hour away, and far from satisfactory transit.

Consider that transportation preferences become ingrained as we age. The factors in the upper right quadrant would increase the likelihood that a young non-owner would remain a non-owner for life. Creating a sustainable social environment for Chase's Heaven would likely have longer reaching effects than would persuading reluctant boomers to change habits in their waning years.¹⁵

4.2.3 Forces Limiting Diffusion of Vehicle Ridership (lower right quadrant)

In addition to the substantial weight of barely addressable, pro-ownership factors (upper left quadrant), many other addressable factors help prevent the abandonment of vehicle ownership and keep the brakes on the subsequent adoption of ride consumption.

The changes needed to nurture new mobility carry risks due to unfamiliarity and complexity, and are challenged as well by the limited functionality and high expense of early-generation robo-vehicles. These vehicles also generate fear regarding change, jobs, privacy, safety, and personal security. Regardless, industry will be innovating robo services to compound the ROI from its substantial investment in automation. The automotive industry is a puppet-master to human desires — they will either be a formidable partner or a daunting opponent on the road to Heaven. Notice who won the car-versus-bus contest over the past 120 years, even with a period within these decades of the auto industry promoting motor buses over electric street railroads.

History often repeats. Without appropriate preparation — and especially if industry takes over vast tracts of transit — change will not automatically promote social equity. By default,

corporate service offerings tend toward cherry-picking opportunities that maximize the financial return to shareholders.¹⁶

But the changes needed to ameliorate the negative factors in this quadrant are not difficult to understand, even if challenging to implement. One way is systems that gradually move from limited “last-mile” robo-shuttles toward robust, regional, robo-transit systems over the next few generations of vehicle automation. [Grush 2016, p.45] Another way is focused civic leadership designing and implementing public policy to safeguard social equity, transit-oriented jobs, urban-planning objectives, and transportation-supplier profits while dramatically increasing robo-transit ridership. [Ch. 6 & 7] Indeed, both approaches can be collaborative and effective concurrently.

4.2.4 Forces Limiting Diffusion of Vehicle Ownership (lower left quadrant)

There are many factors that may discourage ownership but have had only weak effects to date. Owners that rely on their vehicles for accessing jobs continue to absorb creeping inconvenience and cost. They can keep cars longer, run them in poorer condition, circle for cheaper parking, and buy used vehicles. The fact that household vehicles are “95 per cent idle” and a wasted asset is an influence that drives sharing-economy advocates preaching-to-the-choir far more than it influences the market-selection processes of existing car-owners. After all, most of us own very few personal physical assets that we use more than five per cent of the time. Why? Most of us own such assets to make our lives more convenient. Family cars are hardly a good financial investment per se, and that is not why we own them.

Land-use regulation that increases demand and the price of housing has an unintended effect when families decide to purchase affordable homes that demand increased car use and ownership. Growth in the adoption of household semi-automated vehicles will facilitate more suburban home-buying. And this prediction has a growing chorus of recognition.

Eco-consciousness while a factor for a few is not a game-changer. The human species is socio-biologically wired for individual and small-group success, in that order. Car owners will choose what they perceive as best for themselves and their family. Absent suitable alternatives and appropriate pricing-signals, the health of the planet’s atmosphere is the last thing on most car-buyers’ minds when visiting the show-room floor.

4.2.5 Some Time in Hell before Heaven

Worldwide demand for personal travel continues to rise with wealth and population growth. [Dargay] This economic force will overwhelm any early shifts in average ownership preferences, even as the absolute use of shared vehicles begins to ramp up in particular locations. Overall, in the 2020s, the massive world population of privately owned vehicles will continue to grow, even as single-digit sharing may begin to grow even more rapidly. Because sharing systems need many more than just a few people willing to abandon ownership, sharing will initially pool in small, select geographic and demographic pockets, and be especially popular among existing consumers of taxi, bus, ride-hailing and carshares.

At some point (the mid-2030s, according to the robo-taxi evolution forecasts of Roland-Berger [Bernhart] and Deloitte [Corwin]) we should expect to see a plateau in ownership, and rapid growth in the deployment of robo-taxi and shuttle services. Only when that occurs can there finally be an absolute decline in registered vehicle counts, as vehicles are replaced with high-turnover, public service vehicles, perhaps idle less than 50 percent of the time.

In the report preceding this one, [Grush, 2016] we looked at ways municipal leadership can accelerate the most suitable social steps for what we see as inevitable technical and market revolutions by proactively creating robo-friendly residential and commercial zones and combining them with trial deployments of available robotic vehicles aimed at generating the changes and data that would improve the market embrace of the civic vision.

In Chapters 6 and 7 of this report, we will look at ways governments can promote urban/social regulation in a way that encourages commercial robo fleets to grow while enhancing livability, social equity and fleet profitability.

5.0 BARRIERS TO SHARED USE¹⁷



Frequent assertions that car owners will easily abandon ownership and become robo-vehicle ride-buyers are largely wishful and without sufficient evidence. How much travellers tend toward increased (or sustained) vehicle ownership, and how much toward car- and ride-sharing depends as least as much on human behavioural preferences and habit as on pure economic considerations.

Two great myths surround vehicle automation. The first is that this technology will drive traffic congestion out of urban road transportation networks. This cannot happen soon for four reasons:

- ① Human populations are still increasing.
- ② People continue to migrate to cities and tend not to abandon vehicle ownership and use.
- ③ Infrastructure investments are less than what is required to have free flow given current urban Canadian land use patterns, trip habits and travel decisions.
- ④ We face two to four decades of mixed traffic — non-automated and automated — which will delay wide-spread deployment of platooning, lane narrowing, intersection optimization, and dramatic downsizing of street parking that are among the promised advantages of driverless vehicles.

And the mitigation of congestion cannot happen easily for two more reasons:

- ⑤ An increase in road capacity generally induces more traffic.
- ⑥ Congestion is often a measure of success or desire: we crowd near things we want and on roads that take us to preferred places. No matter how cleverly cars are sized and connected, or how brilliantly they coordinate and swarm, surface vehicles occupy road space and competition for that space will not cease. Congestion is its own feedback loop — it tends to fill up space made available and becomes gradually self-limiting as that space fills up, although certainly less effective at self-limitation than it is at filling up.

Whenever goods or services become more efficient or less costly, humans tend to consume more. Given a self-driving vehicle, some people will prefer to live further from the city core, especially if central housing prices remain increasingly out of reach for so many (the drive toward higher density is also a somewhat self-limiting system). Everywhere that mobility becomes easier or more efficient on a personal basis, more vehicles will show up. The success of on-line shopping has put more goods vehicles on the road, which some claim moots the net effect of online commerce in reducing road traffic. [Zaleski] However, other evidence says this may not be the case, [Schmitt] serving to dispel the certainty with which popular media portrays current traffic circumstances, much less future scenarios.

As well, we could never afford to build and maintain enough capacity to be forever congestion free. Only a significant decline in VKT accompanied by a sufficient improvement in technology will reduce congestion, and a long-term, permanent decline in VKT is not predicted as long as road pricing with high peak and lower off-peak prices is considered anathema by most of the North American population. Freedom from congestion is not in our immediate future, and it will certainly not “just happen” because cars become driverless.

“Car ownership will survive. Car purchase and usage decisions are separate, and there are many reasons not to give up our cars. We forecast global car sales holding firm and rising slightly to 100 million in 2030 vs. 87 million today, helped by rapid turnover of ride-share cars, in spite of declining car penetration.” — Burgstaller

5.1 The Ownership Question is More Important Than Automation

The second great driverless-vehicle myth is that “no one will own a car.” It may be reasonable to expect a relative decline in per capita ownership, but to date there continues to be an absolute increase in total ownership.¹⁸ Since urban space is constrained, an absolute increase — which many mobility optimists ignore — tends to overwhelm any relative decline that may occur. That private ownership will cease or become rare is wishful thinking — at least for the next half-century and for any country whose government will not ban ownership.

The effort required to convert the majority of vehicle owners into ride-buyers will be far greater than the effort to turn the current population of drivers into users of automated vehicles. The best we can hope for is to gradually reduce vehicle ownership thereby reducing absolute vehicle numbers, not just per capita numbers. But significant reduction in private ownership will not happen until robo-ride services are clearly better than current ride services including being an improvement over the perceived serviceability of private ownership. Humans change behaviour when forced or when the replacement behaviour yields a better personal outcome by a significant amount. According to behavioural economists, “the pain of losing is psychologically about twice as powerful as the pleasure of gaining.” [Samson, p.111] If giving up personal car ownership is psychologically framed as a loss, then *loss aversion* would effectively prevent vehicle owners from abandoning vehicle ownership until it is reliably and overwhelming clear that robo-ride services are better in the domains for which each such owner sees ownership as valuable.

Having a cheap robo-taxi able to take you to *some* destinations — the initial service expectation for select locations in the 2020s — is insufficient to have most car owners abandon ownership. Having a wide-variety of vehicles take you literally *anywhere* after only short wait times and with clearly lower costs and in a vehicle the trip-taker judges as comfortable might convert many more vehicle owners into users of shared vehicles. But how long will it take for this service level to be achieved?

Forecasts are frequently made that robo-taxis will be cheap and will arrive within a couple of minutes of being summoned. It is easy to imagine that they will be cheap — less than today’s taxis or even ride-hail vehicles, and even less than owning your own vehicle — but will the fares be below the subsidized cost of taking the bus?

This is notably questioned by Burgstaller et al.:

Although the driver accounts for close to half of per-mile ride-hailing costs, we do not think that the arrival of autonomous cars will bring correspondingly cheaper ride hailing. Asset-light ride hailing have little interest in entering the asset-heavy fleet business, a situation that could open up the biggest revenue pool in new mobility: autonomous fleets. The autonomous fleet business is potentially transformative for OEMs. — Burgstaller

Furthermore, to have driverless shared vehicles always arrive within a couple of minutes will require a large, carefully sized and orchestrated fleet and will not — in the early decades of automated vehicles — be practical everywhere as user densities vary over urban geographies. Both “cheap” and “immediate” are bold claims that are easily (and often) simulated in the lab, but harder to substantiate. Until this kind of performance is verifiably demonstrated in vehicles of sufficient personal suitability on city streets in the wide variety of weather, festivals,

evacuations, and other event conditions that drivers confidently know how to confront when driving their own cars, a majority of vehicle owners are unlikely to abandon ownership.

5.2 Environmental vs. Personal Choice

But, are affordability and instant arrival even the prime determinants? According to a 2017 survey of 2,320 holders of driver licenses from 15 countries, “the majority of those who drive ... choose their car because it’s the most *comfortable* option.” In the same survey, the importance of *speed* was clear: “70% ... say they’d be more likely to use public transport if they had a faster journey time.” [Averkamp]

The ideal fleet according to the environmental and livability perspective comprises vehicles that are *automated, connected, electric, and shared* — ACES. The ideal fleet from the common traveller’s perspective would have vehicles that are *comfortable, affordable, fast and instantly available* — CAFI. Sharing of cars or rides would only be acceptable to CAFI thinking — if ever — when it makes access to rides more affordable, reduces parking hassles and does not slow down ride commencement with long wait times. The ACES-CAFI difference is the divide between what planners wish and consumers want. This gap is now very wide. It must be closed to achieve the Holy Grail of having most people use “mobility as a service” (MaaS) rather than owning their own vehicle.

Shared CAFI robo-taxis sound more desirable than ACES taxis as an enticement to abandon ownership. Alas, automated CAFI is much farther off than ACES — likely more than a decade just for innovation. Even if CAFI vehicles were to become pervasive, an agreed definition of “comfortable,” “affordable” and “instant” would be elusive. Surely, any city will have travellers willing to use robo-ride services, and it would be reasonable to expect a slowly-growing segment of the population to not own vehicles, but projections of 25 per cent of PKT by 2030 or 80 per cent by 2040 in on-demand robo-taxis are wishful thinking unless we can create a dramatic social, regulatory, urban, and technological shift. Vehicle automation by itself will not be enough. Rather, as discussed below, we need to think about robotic taxi or shuttle systems that will appeal to passengers with a wide variety of needs and preferences.

ACES and CAFI are not necessarily contradictory, but they are independent of each other. If we focus on deploying ACES fleets while ignoring CAFI, we will have an ideal environmental solution with modest user acceptance. If we focus on CAFI at the expense of ACES we will have higher user acceptance of a less than ideal — and possibly harmful — solution. If, however, we design and manage CAFI fleets that are constrained by ACES technology, we can address both environmental goals and traveller satisfaction. There is hope, but the demand and deployment challenges are higher.

If we have learned anything since the rising popular awareness of global warming, it is that most humans consume what they desire first then maybe think, often in minor, ineffective ways, about possible environmental impacts later. We can deploy whatever robo-taxi fleets we want, but only CAFI fleets will succeed to the extent needed to become pervasive and to be able to draw a majority of users away from personal vehicle ownership.

5.3 The Challenge of Travellers With Non-routine Needs

Even when and where robo-taxis become CAFI, it is important to consider why some individuals and households might still elect to retain a personal vehicle and how these choices might be addressed to increase the portion of automated, shared-use vehicles.

If comfort is a critical decision criterion, then we need to consider what being “comfortable” actually means to each traveller. Trip takers have a wide range of ride preferences and tolerances from exclusive access to a personal luxury vehicle, through cycling and to the backseat of a poorly maintained taxi or standing room only on a city bus. All of us know people who are comfortable taking whatever means are cheap and available and others who refuse to use bike or public transport. Some people are uncomfortable using a taxi or bus late at night. Others are more comfortable using Lyft than the hotel shuttle.

The lead author of this report is more comfortable taking a subway when he has plenty of time, but less comfortable — especially in Toronto — taking transit if he must arrive by a specific time. This may sound irrational, because travel time in a car is often equally unreliable in Toronto, but a personal car creates the illusion of control and at least the rider enjoys personal space— hence greater comfort in that context.

While this anecdote is personal, it is not unique. More importantly, comfort not only means many things to many people, but there are certain issues of comfort — which may include perceptions of safety and reliability — that will ensure some people will continue to own their own vehicle, even if they sometimes use on-demand robo-services. Here are a few others.

5.3.1 Travellers With Children

Young children need to be restrained in car seats that are customized for their age and weight. In most provinces and states, children under a certain age must be secured in a car seat or booster seat in the back seat of the vehicle. [CHP] Canada has strict laws that vary by province. [BCAA] Similarly, child safety laws across the United States vary but in general require car seats for children until they are least five years old (or a certain weight) and in many cases older than that. [BCAA] In the United Kingdom, children are required to use a child car seat until they are 12 years old or 135 centimetres (about 4.5 feet) tall, whichever comes first. [U.K.] Many parents continue to deploy car seats beyond the required age or weight even while car safety laws continue to get stricter. In short, a substantial portion of vehicle passengers needs to be in appropriately sized car seats.

Such safety regulations, coupled with parental concerns for “instant” availability of an on-demand vehicle with suitable seats that are correctly configured and sufficiently sanitary for their child would have most travellers with small children prefer ownership of a personal or family vehicle.

One can imagine new safety innovations, such as more easily installable and highly portable child seats or new sorts of child restraints standard in all vehicles, but until such innovations are pervasive in robo-vehicles, travellers with children will be a major logistical and operational

challenge for robo-taxis. If shared automated vehicles are to be used by this group, a certain percentage of these vehicles will need to have customized car seat configurations to handle young children. For example, for a family with two children aged one and three, the vehicle would need to be equipped with two child seats each of a different size and design. For a family of five with three young children, a different configuration will be needed in a larger vehicle — and so on.

Yet other issues would make travel with children less amenable to robo-taxi use. Child-related commuting often involves multiple intermediate stops (school to after-school program to groceries to home). Unless a parent or caregiver is accustomed to handling this trip on city transit, these stops make it inconvenient and expensive to use robo-taxis. These issues can be addressed, but until such trips are more convenient and cheap, they pose barriers to shared use. This is perhaps reflected in the fact that current ride-hailing services generally do not focus on servicing families with young children.

5.3.2 Travellers Who are Disabled or Elderly

The disabled represent a significant and often underserved segment of the population from a transportation standpoint. This is also true of the elderly who often have minor difficulties getting around, even if they are not disabled, per se. Some disabled individuals are still able to travel independently. Others utilize shared vanpools, private assistance or public transit for trips.

The United States Census reports that nearly 20 per cent of Americans (more than 55 million people) have some form of disability. [USCB] According to earlier data from the United States Department of Transportation, about 23 per cent of individuals with disabilities need some sort of specialized assistance or equipment to travel outside the home. [USDOT] And 65 per cent of individuals with disabilities drive a car or other motor vehicle. [USDOT] A similar portion of Canadian travellers are disabled or elderly, and this portion is increasing. [Hodge]

Since many disabled or elderly individuals are less mobile than non-disabled individuals, projections have been made that automated vehicles would provide new opportunities to the disabled and elderly, permitting those who are aged, blind or have other disabilities to travel more easily and more frequently. Hence, the percentage of VKT by those with disabilities is likely to grow in an automated vehicle world, making the disabled an expanding segment of the trip-taking population. This would be compounded as baby boomers age out of their licensed driving years, even while some remain frequent and independent travellers.

Some disabled car travellers would still require, as now, special fittings, sizes, egress, loading areas, and occasionally human assistants (stewards), whether their mobility is provided by an on-demand robo-cab or a vehicle on-hand that they own. This portion of the disabled and elderly segment would probably — if they have sufficient resources — prefer to have a dedicated private vehicle immediately available and ready to go with installed equipment necessary to let the traveller get into and out of the vehicle unaided.

Of course, disabled individuals wanting to use on-demand robo-cabs who are not able to help themselves into and out of a vehicle — no matter how equipped — would require customized

services and vehicles, adding a logistics challenge reminiscent of today's highly subsidized demand-response services for accessibility. The costs savings achieved by automation would be mooted by the requirement for a human assistant.

5.3.3 Baby Boomer Travellers

Baby boomers pose a related issue as this will be a large, if not the largest, cohort in many jurisdictions in North America during the first decades (2020-2040) of the adoption of highly automated personal vehicles and fully automated robo-taxis. The baby boomers' affinity toward owning vehicles will affect their consumption preferences. Their waning driving capabilities and interaction times may challenge user-interface engineering for highly automated vehicles and their declining physical capabilities will put more pressure on existing programs for labour intensive and inefficient on-demand transportation models for the disabled. This means a large segment of the current driving population may completely skip the purely driverless robo-taxi as they move from private, highly automated vehicles directly into robo-shuttle fleets with human attendants.

There may be opportunities created by integrating mobility devices and the design of automated vehicle and services that would promote aging-in-place strategies, with the accompanying reductions in healthcare cost projections. Savings in health costs and improved health outcomes may fully offset public and personal investments in transportation service technologies. If such a direction is adopted within a shared-service fleet setting, care must be taken to segregate higher service expenses from majority users to avoid nudging them toward personal ownership.

5.3.4 Travellers with Animals

Many individuals travel in their cars with pets, particularly dogs. They travel to the park, veterinarian, work, school and on vacations. [Kadet] The pets usually sit in the back seat, but sometimes on the driver's lap. Because these pets tend to leave odours or hair, some robo-fleet operators may decline to permit pets in their vehicles, narrowing the range of vehicles available for persons with pets and encouraging pet owners to own a private vehicle.

Consider a blind person with a guide dog. A robo-taxi would be perfect, especially since such a person might not have owned a vehicle before and might not wish to start owning one. Will there need to be a special sub-fleet for such users? Or will long waits be acceptable, if such specialized vehicles would be few and far between? Someone recently left a note on the door of a Toronto condominium building the principal author lives in. It was addressed to the city's disabled transit Wheel-Trans service: "I waited for two hours, I had to call my sister to get me. Sorry I was not here."

5.3.5 Travellers Who Smoke (or Have Other Unpleasant Habits)

Similar to the issue of pet owners, some travellers prefer to smoke while travelling in an automobile. It is likely that some fleet operators will decline smoking customers or at least

segregate smoking and non-smoking vehicles, as hotel operators do with their rooms today. Even if a smoker does not smoke during a journey, there will be complaints about odours from the next customer or —worse — from a ride-sharer. Smoking will tend to make some smokers prefer to own their own vehicle. On the other side of this issue, those travellers who are strongly put off by the smell of stale tobacco smoke or other smells may also prefer to own their own vehicle in order to avoid this exposure.

This argument extends to drinking, drugs and other human behaviours that leave smells and sights that others may wish to avoid. A couple of instances of a ride buyer on the way to a business or romantic meeting sitting in an odour-filled vehicle will have such a user consider returning to vehicle ownership or leasing. While these behaviours will not always discourage travellers from using on demand robo-taxis, they will be a deterrent to some. And this “some” may be significant enough to diminish the economies of scale that would otherwise come from widespread adoption of shared use vehicles.

5.3.6 Travellers Concerned About Communicable Diseases

Some travellers are especially concerned with the risk of contracting an illness. Toronto had a pointed experience with this issue in 2003 during the outbreak of SARS, which saw many people avoiding public transit. In some Asian cities, many public places were closed temporarily. We can expect the frail, elderly and the health-obsessed to be leery of some forms of mass transit vehicles, including taxis and shuttles. Many such travellers who are able to do so would prefer personal ownership.

5.3.7 Travellers Requiring Carrying and Storage Capacity

Some individuals require a considerable amount of mobile storage space throughout the day. Gardeners, plumbers, electricians, construction workers and dozens of other service providers carry tools. Sales representatives often carry samples, equipment and signage from site to site. Such tools and equipment are usually too inconvenient to carry on public transit or in shared cars.

Anyone running multiple errands, such as picking up items such as groceries and dry cleaning, has come across the same issue. They often store goods from the first stop in their vehicle before continuing to the next stop. Because of their need to make multiple stops per day and carry large, heavy or multiple items, or picking up kids from school, such individuals will typically prefer to own a personal vehicle with storage capacity in the form of a trunk, back seat, or truck bed.

There are many people who use a vehicle to carry things in the ordinary course of family life — even if only once a week. That either means that robo-taxis will need to accommodate these trips and capacity needs — from stopping and waiting several times during a multi-stop shopping trip or being able to carry a bookshelf home from IKEA. If they do not, some car owners will remain car owners.

5.3.8 The Cumulative Impact of Travellers With Specialized (or Non-Routine) Needs

Every second Friday, a divorced father drives from mid-town Toronto to Scarborough (in the east of the City), 45 minutes each way, to get his daughter from her mother's home for the weekend. She has an overnight bag, a very heavy bag of schoolbooks, an acoustic guitar, and always one other bag of something. Father and daughter then pick up an older sister from another home 15 minutes away, eat at a restaurant after yet another 15-minute drive, drop the sister back to her house, go grocery shopping for the weekend, then finally head off to the father's home for the night. This journey is unworkable on Toronto's transit, could be done inconveniently with three, multi-stop Uber trips, and because of its length and traversal of a long swath of the city, will be a long time before it is handled readily by trip-chaining robo-taxis. The point of this anecdote is that this driver is a candidate for swapping out frequent midtown-to-downtown subway rides for ACES robo-taxi rides when they become available, but he is not a candidate for disowning his car until a full-and-(almost)-everywhere CAFI on-demand service is available. In the initial years of robo-taxis, ACES technology, in constrained service areas, will reduce transit ridership far more than it will reduce car ownership.¹⁹

This list of exceptions to the default, simple, able-bodied commuter with an umbrella and a brief case might have many think: "sure, some people will continue to own a personal or business vehicle, but not most people." This is wishful thinking. The cumulative number of individuals with non-routine needs is high and can be expected to have a significant impact on the adoption of automated, shared use vehicles.

Not only do all of us sometimes have non-routine travel needs— even if only occasionally — a majority of us in the developed world have become accustomed to have access to a family vehicle and most of the rest of us can find a friend's vehicle to resolve occasional outsized needs.

Early robo-taxis will be an excellent service upgrade for those who use transit and taxis now, saving them time and likely money while adding considerable convenience. Robo-taxis are expected to be in common use by 2030 and this may help some families get rid of a second car. But it will take much longer for robo-taxis to dislodge a family's only private vehicle. Vehicle automation will likely not have the desired effect on congestion, parking, sprawl, and urban livability, until shared use vehicles and the urban environment are designed to accommodate those with non-routine needs. Automation alone will not be enough to move the sharing needle more than a few percentage points.

Figure 7: Reasons to Retain Vehicle Ownership, 2020-2035 (Author's Estimates)

Some barriers to shared vehicle use. These and others may outweigh willingness to abandon vehicle ownership during the early years of automation (2020-2040) (author's estimates, not projections).

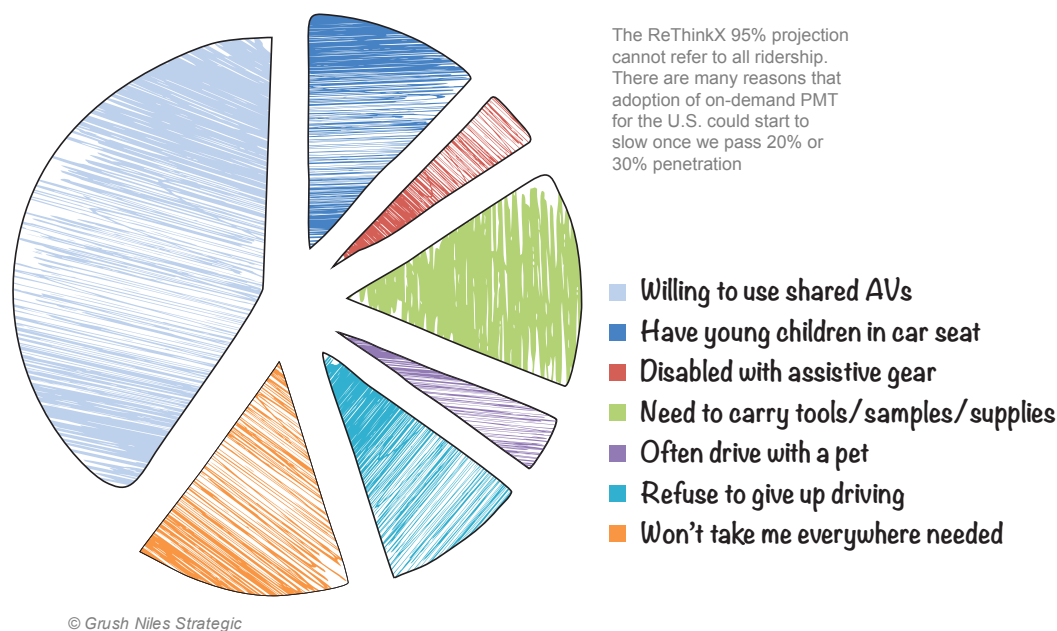


Figure 7 illustrates these observations with estimates constructed by Grush Niles Strategic. They are not formal projections, but have been tempered by a number of recent surveys. [Averkamp; Merat; Zmud] It will likely be feasible to move toward 25% of regional PKT served by automated, on-demand fleets in the 2030s, but it will be more difficult to get to 50% in the 2040s and very difficult to get to 75% before mid-century, if ever. Considering that PKT demand historically doubles every 25 years, and that then-existing taxi and transit users will dominate the first wave of robo-ride users, it is hard to argue that automation will relieve urban traffic woes in the first two decades after introduction.

These exceptions to common optimism for driverless-taxi adoption are neither comprehensive nor are their relative proportions well understood. They are presented to illustrate a sample of non-routine traveller needs and the potential heft and variety of the barriers to giving up personal vehicles. The critical issue is that there are many personal vehicle users whose definition of comfort is difficult to satisfy with a narrow range of robo-taxi service vehicles designed as simple people movers always available within a couple of minutes of a smartphone request.

Much discussion around the impact of shared and automated vehicles is based around users getting to and from work carrying only a briefcase or bag or getting home from a bar after too many drinks. This thinking often orbits around the fact that urban millennials are less likely to be focussed on car-ownership than are other demographic cohorts, hence the default caricature

of a robo-taxi user is the younger, urban, employed, middle-class, able-bodied, Uber user of today. Much less thinking revolves around trip planning for Saturday shopping, taking the dog to the veterinarian, the baby to day-care, or the family to grandma for dinner 60 minutes out of town. Yet such trips are in the future of millennials as well. The more a robo-fleet is configured and managed to address all these users, the harder the logistics become, the longer the average wait, and the more costly the average PKT for the imagined perfect fleet.

Currently, the idealized robo-fleet would satisfy only a fraction of user trips. For every pet taken in a pet-free vehicle or smoker using a smoke-free car a robo-ride user might be disappointed and encouraged to buy a car or join an exclusive car-club, diminishing the pool of riders for massive robo-fleets and the efficiency of massive, relatively uniform, coordinated fleets.

Making the utopian robo-fleet system as flexible and serviceable as the private vehicle is now might make robo-taxi PKT as expensive as current private vehicle PKT. It is worth considering why [Burgstaller] wrote: “we do not think the arrival of autonomous cars will bring correspondingly cheaper ride hailing.”

To have on-demand robo-vehicles persuade car owners to switch overwhelmingly to ride buying, we need to do more than make them cheaper. We need to start thinking about how to design on-demand transportation services — including their constituent vehicles — to make them more convenient, comfortable and accommodate as many non-routine needs as possible. We may also need to consider other changes in the built environment, such as public storage lockers, new forms of wearable or portable accessories to make it acceptable for a wide variety of individual needs to be addressed by shared vehicles. We will then be in a better position to shape a shared use robo-vehicle future.

6.0 GOVERNING PUBLIC FLEETS OF AUTOMATED VEHICLES



Assuming successful technology applications and shifting consumer behaviour, regional²⁰ governments in the 2020s will be faced with governing growing numbers of automated and semi-automated vehicles. These vehicles might be privately owned by households, owned by new or transitioning mobility firms such as Lyft, Uber, Ford, or GM, that would operate them as taxis, shuttles and jitneys, or government operated and sometimes owned by mobility infrastructure investors under public-private partnership (P3) contracts. By the 2030's such automation is projected to be significant, perhaps pervasive, but it will also be challenging, bringing on a decline in urban bus transit ridership, [Ch. 3.10] the potential for service gaps, unexpected congestion due to service redundancies, and risks of poor or negligible coordination with existing rail transit.

There are two common scenarios for the future of automobility as vehicles become increasingly automated. The first is that most North American households will retain at least one personal automated vehicle (PAV), as now. The alternative view is that almost no one will bother to own a personal vehicle because it will be so cheap, easy, and convenient to obtain a ride in a shared automated vehicle (SAV), i.e., a publicly accessible, robo-taxi or robo-shuttle. Note that a contrasting view was offered in Ch. 5 when detailing many reasons some people might prefer to own a personal vehicle.

While the latter scenario occurs to most urban-transportation thought-leaders as the more desirable of the two, this is neither guaranteed to occur, nor has it been determined how such an outcome might be governed in order to achieve a high level of optimization with respect to time, energy and fleet size. In addition, given such fleets, how can we improve aspects of urban livability related to growth patterns, congestion and walkability? How can we ensure social equity with respect to mobility affordability, availability and accessibility for lower income or disabled travellers?

6.1 What Might Be Achieved With Automated Vehicle Fleets?

In one of the most insightful discussion papers of 2016, Tom Cohen and Clémence Cavoli outlined several governance choices and the associated difficulties and risks of preparing for automated vehicles. [Cohen] They contrasted three approaches to fleet ownership:

- ❶ Private-ownership, i.e., business-as-usual, except with automated vehicles.
- ❷ Shared automated-taxi fleets, an essentially *laissez-faire* continuation and growth of today's taxi and TNC approaches.
- ❸ Strong integration of AVs with public transit systems, a somewhat more interventionist approach for improved social and network outcomes. This paper addresses the governance issues and potential pitfalls for each approach.

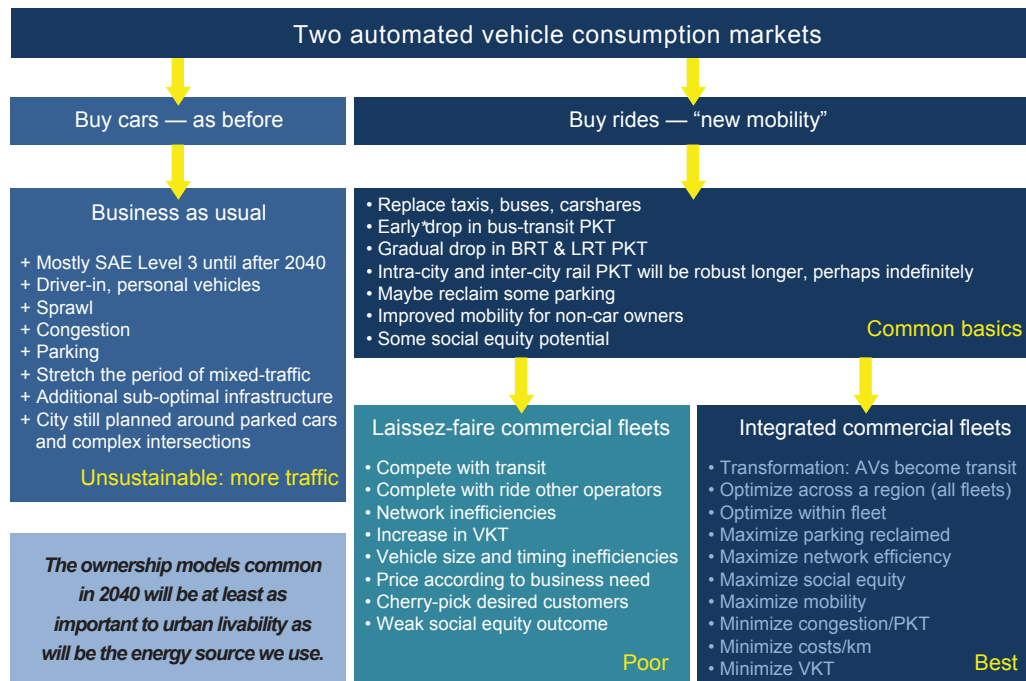
A parallel discussion appeared in a 2017 UITP report outlining the pros and cons of each of the three approaches to the coming regional fleets of automated people-moving vehicles. [UITP] Figure 8, adapted from this report, shows the two major markets: buying cars (PAVs) and buying rides (SAVs) and further splits SAVs into either *laissez-faire* commercial fleets (similar to current taxis or TNCs) or integrated commercial fleets. Each of these have very different social and urban outcomes due to the operating differences in collaboration and coordination, which, in turn, would be due to the degree of private versus public management of the fleets.

To frame the governance problem: how can we most effectively unleash the promised benefits of automation, maximize personal freedom, preserve or enhance social equity, and reduce or at least not increase congestion and environmental harms — all while rewarding for-profit operators who finance and operate massive fleets?

In comparing a *laissez-faire* approach with more interventionist styles of governance, Cohen and Cavoli concluded that while a *laissez-faire* approach would carry the greatest risk, intervening to integrate multiple private fleets with transit might not be palatable for many governments to attempt. In any case, it would be risky.

Figure 8: Two Automated Vehicle Consumption Markets

If we want to encourage buying rides instead of buying cars, we need to understand the governance of massive shared fleets (Adapted and expanded from: “Autonomous vehicles: a potential game changer for urban mobility” A Policy Brief of UITP, the International Association of Public Transport” 2017)



Expanded from: “Autonomous vehicles: a potential game changer for urban mobility” A Policy Brief of UITP, the International Association of Public Transport” 2017

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There are a number of governance challenges with shared fleets highlighting the complex task ahead. One critical factor is that *laissez-faire* commercial fleet operators will act to maximize their shareholder’s long-run or short-run profit. On the other hand, a more interventionist approach to facilitate transit integration could follow public policies to maintain social equity with ongoing government subsidies providing service to citizens judged unable to bear the full cost of service.

A profit-maximizing private provider might ignore equitable geographic coverage and universal access in favour of ridership volumes, but careful government intervention in this business model could be aimed toward balancing ridership volume with equitable access for all sub-regions and citizens. To balance the profit-oriented motivations of fleet owners, appropriate governance structures could promote coordinated integration among private operators and remaining trunk line transit.

Simply “not owning” vehicles is insufficient for the quality of urban mobility sought by most Ontarians and Canadians for themselves and their country. We need to share service vehicles in an intelligent, high-quality manner that encompasses all three dimensions of sustainability — economics, environment and equity.

6.2 Factors to Be Considered for Governing Automated Fleets

This implies that a carefully considered governance-planning model for massive shared automated vehicle (SAV) fleets is important. Some of the critical assumptions for such a governance model would be:

- ❶ The three ownership models outlined in Figure 8 will each continue to have strong proponents; hence financial, spatial, and social competition will be unavoidable and ongoing. We are accustomed to this in the long-standing competition among private cars, taxis, and transit, as well as in goods movement and with active transportation modes. We should plan accordingly.
- ❷ Governments — especially in North America — would be unwilling to ban or significantly limit personal vehicle ownership, notwithstanding that a few prohibit vehicles in central city zones while others employ nudges or high taxes to reduce driving or ownership.²¹
- ❸ The history and reasons for commercial operators to own and manage transportation service fleets are significant.
- ❹ Most local governments would not be financially able to acquire and operate the massive fleets needed to provide a majority of regional trips in SAVs.
- ❺ Most governments would be severely limited by both budget and mandate to offer the multiple levels of service needed to persuade middle-to-higher-income travellers to abandon personal vehicle ownership, while still addressing core social equity²² issues.
- ❻ No specific instance of governance will work in all locations or for unlimited time spans, hence any sustainable model will need to have numerous levers to make ongoing adjustments — critically, it must be able to dial up or down the degree of intervention for reasons of civil acceptability and operational effectiveness.
- ❼ Any workable model must be widely understandable and produce results that are easy to measure.

Most likely, many massive, SAV fleets will be owned and operated by private operators. Hence, the logistical methods to optimize for fleet configuration, energy and network will be guided by cost and profit considerations on the part of these operators. I propose that government jurisdictions distribute regional, performance-based operating licenses to a limited number of participants by auction. The goal of this governance model, then, would be to ensure attention to the elements that a profit-seeking enterprise in this regime might disregard. Further on, I will propose several parameters that put social and environmental concerns on the operator’s ledger. [Ch. 7]

Governance should assume that SAV fleets will be accessed via Mobility-as-a-Service (MaaS) applications so that the differences between *laissez-faire* and integrated fleet approaches will be visible mostly in aggregate and essentially only to transportation managers. Users will be focused primarily on getting to their intended location quickly, comfortably and cheaply. “Comfortable” would convey many individualized meanings. For example, one traveller may take a robo-taxi to the subway, then another robo-taxi to his office to save a few bucks, while a second traveller might simply take a robo-taxi from home to office while working on her laptop and avoid two inconvenient vehicle changes. Users will make choices based on personal preferences and budgets — as most do now — and very seldom for urban livability or broader social equity and environmental reasons.

6.3 Performance Metrics

Governance should incorporate four key performance components — three of which are new — that if properly calibrated would cause many livability and environmental externalizations such as congestion, route efficiency, safety, customer satisfaction, ridership, parking reduction, and regional connectivity to become issues that would be more effectively addressed by fleet operators seeking to maximize profit. These four performance-based elements, more fully described below, are:

- **Higher vehicle occupancy:** Maximize the PKT-to-VKT ratio, i.e., passengers-to-vehicles.
- **Fewer private vehicles:** Maximize the shared-to-private PKT ratio.
- **Safeguard social equity:** Maximize access, affordability and geographic reach for all users.
- **Leverage existing transit:** Maximize connectivity to transit trunk lines, especially rail and limited-stop bus lines in peak periods.

There are, of course, many other concerns such as privacy, security, safety, road and parking pricing where government oversight and good governance are important. Such issues would apply to all forms of automated vehicle ownership. The four performance metrics proposed in this chapter focus specifically on a fleet management architecture to replace the management formula now provided by taxi medallion systems to ensure a constrained fleet size and public access assurance. An additional metric is proposed to preserve connectivity to existing high-capacity transit, as suggested by the UITP report described in Figure 8.

Each of the four metrics detailed below would be incentivized through a balance of subsidies for over-performance and road use fees for under-performance. A digital method to do this for choices specific to a region and for specific submarkets is described in the following chapter. This digital method is designed to be flexible and changeable to comply with changing regional needs.

6.3.1 Higher Vehicle Occupancy: Maximize the PKT-to-VKT Ratio

Designing services that increase occupancy and minimize deadheading can maximize PKT per VKT. Participating operators can address this by optimizing vehicle sizes (fleet tailoring) and

routing, as well as by improving and promoting ridesharing. The numerous ways these things can be done are matters of creativity, innovation and marketing [Hensley] — much of which can be guided by the same sorts of behavioural economic and social nudges that automotive marketers use today.

This is not to say that selling cars is identical to selling rides. We merely assert that given the scale of disruption in this multi-trillion dollar market, motivated companies can find ways to maximize occupancy. Since 2016, both Uber and Lyft have experimented with heavily discounted bulk purchases of ride-share trips that amounted to app-and-reputation mediated jitney services. Offers changed rapidly and now such experimentation continues to be subsidized by the TNC shareholder who is promised market dominance. While promotions for these offers imply competition between these two players, the overall impact of success will affect taxi and bus ridership. With sufficiently large robo-vehicle fleets traversing significant areal extents, service innovations could be designed to increase average occupancy and begin encroaching on personal ownership.

Given a sufficiently flexible governance model to be used across regions with billions of annual customer transactions, creative solutions will arise, especially in the potential for within-operator cross-subsidies between profitable high-end SOV services and coach-class, small group, ride-share services.

6.3.2 Fewer Private Vehicles: Maximize the Shared-to-Private PKT Ratio

The overarching goal here is to move more people in SAVs and fewer in private automated vehicles (PAVs) — all while the demand for PKT continues its year-over-year global average three percent increase driven by the growth in human population wealth. There is a non-coercive way to reach this goal: make individual SAV experiences significantly better than individual PAV experiences for a significant number of travellers so that many car owners would consider switching to ride-buying.

Behavioural economics shows us that there are many reasons people resist change and many reasons why they make economically non-rational choices. Today most people who own cars often complain about driving and parking them, but they do not seriously consider forgoing them for the current spectrum of alternative modes of transportation. Conversely, a person without a car, who currently uses alternate forms of transportation, more often aspires to owning a car. Planners often wish car-buyers would become ride-buyers, even as more ride-buyers wish to be car-buyers.

The reasons most people own cars are understandable. [Ch. 5] If instantly available, safe, clean and comfortable rides can be offered reliably to all destinations that an individual car owner reasonably desires to visit, then a significant number of such car owners may decide to buy rides exclusively. But we are a long way from being able to fill such a promise — and today's fledgling automated vehicle technology is only an enabler. We need focused and intentional programs to design and sustain SAV services that upend the current ownership paradigm.

Early 2020s robo-vehicle services operating in defined areas could potentially replace current shared-vehicle services: transit and taxis. They might compete with PAV ridership somewhat, but will not replace car ownership in a wholesale manner. But after further technological and market growth, massive, robo-fleets with operators motivated to provide reliable, continuous, convenient, 7/24 coverage and access throughout broad regions for every traveller purpose could finally reduce car ownership significantly. This will require coordination beyond the bounds of each town or city transit or taxi service. It will require regional fleets more massive than any single municipal operator can fund or manage and will be fundamentally different from the way public-service fleets are managed and governed today.

6.3.3 Safeguard Social Equity: Maximize Access, Affordability and Reach for All Users

Many public transit systems are routed, priced, and otherwise managed to assure a measure of coverage for lower income families, provide access to mobility for people unable to use normal transit or unable to drive, and grant subsidies for its users. However, such purposes and any related largesse may not readily translate to commercial SAV fleets. Cities currently struggle with this independently and piecemeal as TNC operators such as Uber and Lyft cherry-pick the traditional customers of taxi operators, and more recently, commuter bus routes and even subway transit. [Schaller; Clewlow]

Even for fleets that would provision SAV rides relatively uniformly across a connected region of cities and towns (coverage), the issue of ride provision for all incomes and abilities (access) would be a significant extra step in terms of fare affordability and customer assistance. Governance that ensures a satisfactory level of equity in all of these aspects needs more than marketing creativity or massive systems capability. The level of equity many regions might demand would require oversight and subsidies: these need metrics that are easily understood so that users understand their rights and that both operator and the transit agency overseer can easily agree on performance.

The maximization of social equity is more difficult because it is wrapped in numerous social and political layers. Regardless, metrics and methods of oversight can and must be designed. The struggle will be to agree on the facets of equity to be supported and measured, and these would be tailored necessarily region-by-region. Still a structural guideline across regions and across a country is needed.

6.3.4 Leverage Existing Transit: Maximize Connectivity to Transit Trunk Lines

There are many reasons to believe that transit is threatened by SAVs and even PAVs that attract transit users to these new alternatives. [ch.3.10] One core reason is the economic limits on public transit providing on-demand, 24/7 available, door-to-door trips with a variety of comfort levels depending on the economic resources of the traveller. A three-to-one or four-to-one replacement of city buses with ten- and 12-passenger automated shuttles on more flexible routes and schedules

could mark an improvement over transit services without generating additional congestion at peak. However, the same is harder to argue for the replacement of those buses with 20 to 30 two- and four-passenger vehicles, although this is a potential outcome. Harder still would it be to argue for the replacement of existing rail carriage with such vehicles. It would almost certainly be more advantageous to incentivize the use of smaller-scaled automated vehicles as feeder vehicles into existing trunk lines: rail and express bus trunk lines, especially in peak periods. This is a key point of the aforementioned work. [Cohen; UITP]

The desired level of such integration would depend on a number of local variables. A governance model which rewarded connectivity to existing transit trunk lines would be able to leverage massive sunk investments and to constrain the volume of independent vehicles moving in and out of the urban core at peak times. This could be done with pricing, or managed lanes, or outright area-based restrictions. Many people would prefer pricing nudges to restrictions or outright bans.

One of the unknowns facing regions as they consider integration of automated small vehicle systems with existing fixed trunk lines is the degree to which passengers are willing to switch conveyances at least once for each such journey. One of the fears is that for shorter trunk-line distances, passengers might find continuing in a vehicle that collects them at their doorstep to be more convenient than transferring to transit. This might be an area of optimization conflict for any operator that can gather multiple people into small vehicles, take those passengers to their destinations without connection to trunk lines then to collect other passengers without deadheading to maximize the PKT-to-VKT ratio. More modeling and service deployment experimentation is needed.

6.4 Sharing: Neither the Default Start-state nor the Sole End-state

For this discussion, we simplify ownership models into two critical categories: private and shared. Combining the two non-owned scenarios described in the UCL and UITP reports (*laissez-faire* and *integrated*), SAVs may be operated in an on-demand fashion such as one imagines for robo-taxis or in a transit-like fashion such as regularly scheduled buses and shuttles of various sizes on fixed routes or in jitney-like fashion within delineated neighbourhoods, or as first/last mile systems connecting to trunk lines. We make this simplification because we believe that with the right incentive structure each of these styles of operation would find their own appropriate deployments in neighbourhoods, between residential and working zones, and among centres of commerce in a self-levelling regional balance. This can evolve from incentive-based governance rather than with rigid and scheduled planning using constrained service classifications or per-vehicle medallion approaches. Nudges rather than mandates. Honey rather than vinegar.

We assume that all publicly available SAVs will be regulated in some way. Optimizing a regional shared fleet is desirable in order to achieve the four desired impacts, described above, while readily providing all the shared-vehicle PKT demanded in that region.

We assert that travellers will always seek ways to satisfy their trip desires and will prefer not to make compromises within their personal tolerances for time, cost and comfort. When these are

not satisfied by SAV services, all travellers that can afford to do so would elect to own a PAV — i.e., basic personal travel expectations habituated over a century of expanding vehicle ownership will continue to be satisfied in whatever way each individual finds preferable and affordable.

No reliable forecast exists for the mix of vehicles or vehicle ownership for 2050 or 2070. It can be assumed, however, that there will always be some portion of vehicles that are privately owned. Some will be government operated such as rail or heavy trunk lines or special passenger service vehicles, and many will be operated within commercially managed robo-fleets. The desired goal is a governance system that is flexible enough to permit varying likelihoods of ownership even if/as we move toward a higher SAV-to-PAV ratio. We assume that there will never be a world of only SAVs, and that the SAV-to-PAV PKT ratio would not likely exceed three, i.e., 75 per cent shared. We claim this from considering the realistic requirements for carrying special personal appliances, work tools and loads, children in car-seats, or other preferences for personal comfort or privacy. [Ch. 5]

6.5 Anticipating 2030-2040

We begin by assuming cities in the very near future will be little changed in densities, distribution of residential and employment zones, and commuting distances. There might be a reduction in street parking and an increase in sprawl, but cities — and people — change slower than does the pace of technological innovation. In 2030 the GTHA will have 1.5 million more people, [Ministry of Finance, p. 40] and more housing units, on average shrinking slightly in size. Based on Places to Grow intensification targets, average densities will increase, along with some outward growth. Congestion will likely be worse especially because the GTHA's multi-decade shortfall in matching transportation infrastructure to demand will not allow us to close the gap as population growth continues.

We expect that SAV fleets would comprise vehicles of the sizes and speeds as we have now, suitable to existing roads and mixable with pedestrians and bicycles. There might be a reduction in the average vehicle size; there would be new designs and most will be electric.

Despite the expected progress in a relative downturn in personal car ownership, trip-takers in aggregate will continue to use motorized conveyances at least as much as now and for much the same spectrum of purposes. Many urban populations will continue to grow. Travel per-capita might occur slightly more or less often and for somewhat shorter or greater distances, though always influenced by the reality that humans tend to consume more of whatever becomes more economically available. Entrepreneurs continue to create place-based experiences that masses of people want to see, hear, and taste in person.

Commuter rail, subways, and light rail transit would still be in critical use for high-popularity peak visitation seasons and daily commuting hours. There would not be significantly more or fewer of these high-capacity systems although they could be upgraded, automated, expanded, and rescheduled.²³ In other words, we anticipate a highly recognizable urban world with two changes: (a) many vehicles won't have drivers and (b) *per capita*, individuals and families will own or lease fewer private, motorized vehicles for travel on public roads.²⁴

Of course, there would be many other ancillary changes, and it would likely take until after 2050 to get to an anticipated “mostly shared” state, but let’s just jump ahead for now, since we are merely assuming in this discussion one of the two most commonly described automated vehicle future scenarios.

6.6 Sizing a Massive SAV Fleet

In 2016, the consultancy Roland Berger projected that 27 percent of all PKT globally will be provided by robo-taxis by 2030. [Bernhart]

It is feasible for an urban region to supply a quarter of all motorized, surface PKT in shared, automated vehicles soon after the robo-taxi becomes reliable and capable of serving most areas of the region. In many cities in North America and Europe between 10 and 25 per cent of all PKT are already taken in vehicles that are not personally owned: bus, train, taxi, carshare, hailed ride, or airport limo.²⁵ As I argued in the 2016 report, early consumers for robo-taxis will already be users of shared vehicle modalities — disruption always hits the markets first that are most poorly served. [Grush, 2016] This first 25 percent would be low-hanging fruit since non-private (shared) modalities — and the second family car — will be disrupted by the robo-taxi first.

Regardless of the time-accuracy of, say, a 25-per-cent prediction for any particular region, such a milestone will surely come to pass. As a thought exercise, what might such a fleet look like for the GTHA if it reaches that portion circa 2030? How big would such a fleet be? What might it cost?

The estimate in Table 1 says to serve a mixed-sized peak travel fleet of 152,000 robo-vehicles to move 25% of the GTHA population over an annual 25.5 billion passenger kilometres will cost \$10.1 billion per annum in 2030, employ a staff of 30,500 and cost 39 cents a person-kilometre to operate. Such a system could replace all the bus and taxi systems in the GTHA, but if integrated with then-existing rail systems might be achievable at a lower system cost and with a lower congestion impact.

A figure of 39 cents/PKT is considerably lower than the current average per km cost for a Canadian personal car VKT, which of course depends on the vehicle value (depreciation) and parking costs among many other factors. This is certainly far lower than taxi, TNC, or the cost of an unsubsidized transit trip. Insurance costs, road-use fees, rising parking costs, profit-taking and potential security expenses would increase this 39-cent estimate as a final user fare, or the estimate could drop further as technology improves, vehicle costs fall and staff/vehicle labour ratio drops. Other forms of revenue (data, advertising, commercial services) could help suppliers lower average PKT fares, especially during the expected flurry of competition to gain market share. Retail operators may offer free trip kilometres for shoppers, while entertainment operators might offer a ride to the game or show as part of the ticket price. Some employers might make bulk travel purchases for their employees’ MaaS wallets.

Table 1: A Rough Calculation of Expected Fleet Size, Estimated Costs to Service 25% of the GTHA PKT with Robo-Vehicles Circa 2030

GTHA population 2030 (projected)	8.5 M
25 percent of pop (Roland Berger suggested 27% of PKT in robo taxis)	2.125 M
Annual PKT per person (less than current U.S. 13,500 VKT to be conservative for ride-buyers, assume ride buyers purchase fewer km than car-owners travel)	12,000
Total annual PKT for 25%	25.5 B
Current per vehicle occupancy (in passenger vehicle (U.S.))	1.59
Total annual VKT for the 25% at this (current) occupancy	16 B
Target occupancy (mixture of 2-, 4-, 6-, and 12-person vehicles comprising 50, 25, 20 and five percent of the fleet respectively, and operating on average at 50% occupancy (including deadheading which means 55% occupancy when occupied if deadheading is at 10%))	2
Total annual VKT (by converting PKT to VKT at the target occupancy)	12.75 B
Daily duty hours of a vehicle (estimated: daily work cycle including deadheading and waiting for riders; excludes charging, parking when not in use)	16
Speed km/h, <i>estimated from current transit ~2015</i> (top vehicle speed is the posted speed, but most actual travel is in-city, with traffic stops, pickups, waiting, heavy traffic, lights, etc);	24
Daily km potential: all in, stops, pickups, top speed, etc. (duty cycle x speed)	384
Annual km (daily km x 365) (This may be high at first, so larger relative fleet may be needed at start ...)	140,160
NYC taxi annual (for comparison only; this indicates that 140,160 is only slightly high, since robo vehicles are more optimized than human-driven)	112,000
Floor estimate: Number vehicles to cover total VKT; assume perfect operation, average day	91,000
Ceiling estimate: assume 15% (of the ride-buying 25%) of the population is in a vehicle at the annual peak hour, the fleet would need to serve 3.75% of the population concurrently	159,000
Peak-to-Average estimate: use 1.6 x floor [Sweet] requires 146,000 vehicles. (The factor of 1.6 was taken from a traffic study of the Toronto area (this accounts for annual or weekly peaks, not the annual peak!))	146,000
Calculated estimate: the average between the ceiling and the peak-to-average . Such a fleet might incur slightly longer queues at some annual peaks (Christmas shopping, Halloween night) but would have spare capacity to meet short-wait promises, otherwise (Note: <i>there is no buffer for vehicle failures or scheduling and distributions shortcomings.</i>)	152,000
Average annual vehicle cost (capex+ opex+ 0.2FTE @ 80K) * * Assume Capex and Opex (excluding staff costs) for a vehicle is \$50,000 per annum including support equipment. Assume fleet operations (fuel/energy, management, payment systems, security, police and emergency, maintenance (repairs and cleaning), oversight, stewards on the minibuses, map maintenance, roadway watchdogs) require 1 FTE per 5 vehicles. Average staff salary and overhead per FTE is \$80,000 per annum, or \$16,000 staff expense per vehicle (30,500 jobs for a fleet of 152,000).	\$66,000
Total annual cost given above peak, but no buffer; implies occasional waiting times	\$10.1 B
Cost per PKT (no contingency, no profit)	\$0.39

The Leverage of Massive Fleets: Optimization

- What would happen if we could nudge vehicle occupancy by 1/10th of a passenger from 2.0 to 2.1? In this fleet calculation it shaved \$480M from total annual costs — two cents from each kilometre. The leverage from optimizing massive fleets is unparalleled.
- A variety of network optimizations could be made for route, schedule and load distribution across all vehicles — subject to user demand and including the distorting effects of personal preferences. Add creative service packages and behavioural nudges to increase and distribute demand and costs can be decreased to lower the effective PKT cost below 39 cents.
- Imagine a P3 operating such a fleet designed to be responsive to a peak demand — say the peak demand during the six peak hours of the last shopping day before Christmas. This operator would be guaranteed to have spare capacity the other 8,754 hours of the year. Those vehicles could be used to move first/last mile goods using ancillary robotics now under development or not yet even dreamed of.

The Leverage of Massive Fleets: Jobs

Total employment for the first 25B PKT in this 2030 scenario would roughly match the current total equivalent employment for transit, taxi, TNC, carshares, since these early-adopter kilometres are largely replacing labour-intensive PKT in public service vehicles. However, relative employment for the second 25B PKT would begin to *increase* (relatively), since by then the expanding robo-fleet would be replacing the declining effort of the household owner/driver, who is by then being replaced increasingly by fleet operator service staff.

No matter how advanced the technology, these fleets will require human staff far into the future. There will always be a staff cost to have a vehicle arrive within a few minutes of your demand, drop you off safely at the right spot and speed away. Certainly, by the time 50-75 per cent PKT penetration would be achieved in public service robo-vehicles, aggregate job volumes for all public transportation services combined will be higher than current equivalent employment volumes even as the staff-to-vehicle ratio declines.

6.7 The Performance Opportunity of Massive Fleets

Rather than create a new form of medallion system for the coming SAV fleets, local and regional governments have a remarkable opportunity to innovate a replacement for this system: performance-based fleet licenses auctioned to bidders who bid for kilometres of road access paralleling the way in which governments auction radio spectrum, today.²⁶ The following is an example of how it could work.

Operators of automated fleets would bid for access to existing roads in tranches of, say, 100 million kilometres. They would agree to an expected per-kilometre fee (essentially a road-use fee) for access to this road space to operate their business. Associated with the agreed fee would be a number of rules:

Competition. No single bidder can bid for more than 20% of the available kilometres on auction. This will help to maintain a competitive market.

Complexity. No bidder can bid for less than 10% of the available kilometres. This limits user confusion, unreliable bidders, and undue integration complexity. Together, these constraints would result in five to 10 transportation suppliers.

High occupancy. Regional governments set a target average occupancy rate and operators are assessed higher road use fees or subsidies depending on their occupancy performance. This promotes innovation for ridesharing and rewards the bidder with lower vehicle counts to consume the kilometres bid.

Social equity. Winning bidders would pre-agree to a social-equity formula. This would be an agreement to service a given fraction of low-fare customers (this might be subsidized), and a given fraction of less-desirable service areas. Since winners would likely be for-profit operators, they will be encouraged to offer higher-end services to wealthier travellers at higher profit margins to offset their social equity commitment that might have a negative profit margin and thereby access potential subsidies. For example, they may optimize fleet turnover to cascade older or lower-status vehicles into lower-fare service to realize targeted subsidies.

Connect with transit. Winners would pre-agree to a given fraction of connections with existing transit stations or hubs, then optimize service offerings and trip discounts to hit or exceed those targets thereby triggering further subsidies.

Rewards. Winners who exceed occupancy, social equity or connection targets can also be promoted on ensuing bid competitions. Those failing to do so are penalized on following bids.

Attract car owners. In order to compete, winners would be inclined to expand their user-base beyond existing users of taxi, transit and carsharing. They would seek to offer services that would attract car owners to consider owning fewer personal vehicles. (This is a measurable effect, but not necessarily a performance metric.)

6.8 What Would Happen Without Region-wide Fleet Governance?

Fleet optimization on the scale of billions of kilometres is unavailable when city fleets comprise a few thousand buses, taxis, and carshare vehicles — all competing. But such optimizations are second nature to the thinking of private companies that understand logistics and artificial intelligence, exploit big data and telecommunications, have marketing expertise, and enjoy skilled access to social platforms.

There is nothing surprising in this to people such as Uber's founder Travis Kalanick, Ford's new CEO Jim Hackett, or Morgan Stanley's Adam Jonas. [EVWorld] In fact they are counting on this. Digitization and automation always provides advantages to exploiters. Transportation is no different. What has been happening to newspapers, music, retail and taxis will now happen to our municipal and personal transportation systems, threatening both Big Auto and public transit.

Left to compete in the 20th century world of proprietary information stovepipes, companies and cities would continue to operate in an uncoordinated world of multiple taxi, bus and carshare fleets targeted at different demographic groups or regions. When you called for a taxi in the pre-Uber world there was almost always a competitor's taxi closer to you, but there was

no way for you to know that. Uber bridged that information barrier to a limited degree. MaaS apps — such as Whim from MaaS Global — are poised to finish the job by choosing the best option from all user-acceptable suppliers at the time of demand.

The current world of every driver for himself — the core of today’s surface transportation reality — implies urban transportation systems of incomprehensible non-optimality mixed with struggling transit systems. This is the world’s largest market mostly wasted in execution. According to Adam Jonas, “... a century-old ecosystem being ogled by outside players hungry for a slice of a \$10-trillion mobility market. Many want in. It’s just beginning. And it won’t stop.”

For these reasons a new governance system for public conveyances is needed as this privatized and optimized technology pushes existing mobility systems aside. Thus the concept of a “harmonization management system” is developed in the following chapter.

Lyft recently launched Lyft Shuttle in San Francisco with fixed routes and pickup locations, remarkably like a city bus service. One of a growing array of services offered by private new mobility companies, the emergence of these options is good for commuter choice—provided we can protect the traditional role of public transit. (Noting how Lyft Shuttle in San Francisco strategically avoids low-income areas, [Spencer] warns that private bus-like services will exclude less-affluent riders, furthering transit inequities.) But there's another, hidden problem: When a passenger decides to take Lyft Shuttle instead of transit, she is moving more than her money from public transit to a private company—she is also moving data about her trip. But no private transportation service today provides local government with point-to-point information about their passengers' rides. The result is transportation policy that cannot be optimized to serve residents.

That's the position today's planners and transportation executives are in. (Note: Uber makes some ride information available through Uber Movement, but only by neighborhood and average trip time, not specific locations or individual rides). Such data limitations can constrain many policy decisions, such as curb management, implementing road diets or closing lanes during construction. The National Association of City Transportation Officials (NACTO) has published data sharing principles for private transportation companies, but current practices fall far short.

There are several reasonable arguments to explain why these companies can't simply hand over individual trip data to the public sector. Issues of passenger privacy are at stake, and valuable business information could be leaked to competitors. There are simply too many one-off data requests from local government for the private companies to comply with each one—and government staff may not know how to analyze and understand the data even if they have access to it. Each of these arguments has merit. But as private services like Lyft Shuttle develop and scale, city officials are forced to base policy decisions on data derived from public sources, and that information is becoming less representative of residents' total trips.

There is a path forward. All providers of transportation services—public transit agencies as well as private companies—would hand over anonymized trip data to a trusted third party that would standardize it and ensure user privacy and trade secrets are not revealed. Researchers, city officials, and company employees could then access the data and analyses. And the public would benefit from more data-driven policy.

If the rapid ascent of shared ride-hailing shows us anything, it's that private mobility providers are poised to handle a bigger share of total urban trips in the future. We need that data.

Excerpted and edited from a July 2017 article in City Lab [Zipper]

7.0 HARMONIZING AUTOMATED AND COMPETITIVE FLEETS

Digital mobility and vehicle automation are expected to reduce roadway crashes and fatalities. Unfortunately, without a new governance model for personal surface transportation and transit to match these capabilities, they are less likely to reduce congestion and sprawl. Without such governance, they are also unlikely to reduce the impact, free up parking space, improve social equity, expand access, increase trip availability, and improve urban livability.

In November 2016, the Canadian Council of Motor Transport Administrators (CCMTA) published one of the numerous current reports outlining requirements for regulatory guidelines for automated vehicles. This report provides a good example of the common shopping list of issues that need to be addressed before this technology becomes pervasive. Among a sizeable selection of issues in this report, several stand out for study and reformulation. Among these are: cyber-security, emissions, enforcement, infrastructure budgets, licensing, privacy, provincial responsibility, public awareness, public transportation, safety, technology harmonization, testing, and vehicle registration. [CCMTA]

All of these issues and the others listed in the CCMTA report need attention. Taken together, this will be a daunting task and not something that will be settled by 2020 or 2024 when these new vehicles are projected to become suitable for public consumption. Technology often outpaces regulation. Furthermore, regional regulators tend to compete with others “to be the leader” and to be first to “bring innovation” to their jurisdiction. There will be disappointments.

Four months after the CCMTA report was released, the Center for the Study of the Presidency and Congress (CSPC) underscored the gap:

...there must be a willingness among policymakers, regulators, and other public leaders to admit that there is much that we still do not know about the autonomous vehicle landscape, and that applying regulatory measures to what remain hypothetical concerns is premature and likely to stifle needed innovation. Instead, we must approach the autonomous vehicle future with an open mind, aware of its benefits and ready to ensure that technology, innovation, and enterprise also drive advances in safety and reliability. [CSPC]

In the meantime, provinces and states that do regulate vehicle automation, generally insist on a vigilant driver with his hands on the wheel. Of course, this stance is understandable, but there is an unintended contradiction. However confident we may be that the technology train is about to leave the station, we can be equally certain that regulators will not have found a way to climb aboard.

What should give us pause is that much of the U.S. and Canadian description of the regulatory concerns in these two reports focuses on how a new status quo for automobility could or should be regulated as an improved replica of the current status quo — a new world of mobility dominated by safer vehicles and a default of private ownership. This is less so in the European Union where automated vehicles are more often seen as something to be integrated with public transit to serve the public good and urban livability.

Of course, issues of safety, security, licensing and testing are important both for challenges such as distracted driving, and for opportunities such as vehicle sizing or occupancy. But in addition to the attention that status quo regulation already sorely needs there are new, less familiar layers of regulation suggested to us by digitization.²⁷ The importance of these system issues needs to be promoted as well.

7.1 Harmonization: The Opportunity

In May 2017, the Institute for Transportation & Development Policy (ITDP) and the University of California, Davis released an illuminating report detailing a number of issues specific to automated, electric and shared vehicles and the opportunities and regulatory impacts these three technology components enable. [ITDP] Now, regulating many of these has become especially amenable to digital methods.

The list below, compiled from this report, suggests one of the most powerful and immediate opportunities that regional governments have with respect to new mobility: to conceive a new regulatory layer that optimizes the provision of mobility according to jurisdictional authorities operating in a political milieu. This optimization would come from authorities seeking targeted levels of geographic access, trip availability, social equity, and integration to existing transit hubs in a way that encourages significant private investment under public governance and meets other policy objectives.

It is unlikely that such a list would be enthusiastically supported in its entirety by a majority of people. For example, many might agree that ride sharing would help, while objecting to its regulation or government investment in its promotion — especially in jurisdictions that have a significant automotive manufacturing market. Those who agree to its promotion might reasonably doubt that it would reach much beyond 1%,²⁸ thereby considering it attractive, but chimerical.

Regardless, this list is a placeholder for the eventual set of policy levers a region might end up embracing — each region or city *preferring its own subset, weighted in its own way*. How could any such policies be fostered or encouraged in a new digital mobility marketplace?

Table 2: A Selection of Policy Levers in Managing Urban Vehicle Usage for Urban Livability (ITDP)

1.	Monitoring and managing the ratio of ridesharing to single-occupant rides.
2.	Influencing the level of private ownership of AVs in the region.
3.	Setting levels of resources to promote trip sharing & use of public transport.
4.	Regulating the competitive market for mobility as a service.
5.	Influencing energy efficiency through subsidies and taxation of vehicle fuels.
6.	Monitoring the labour and equity impacts of automation.
7.	Regulating air emissions from automated vehicles.
8.	Setting policies to protect private travel data.
9.	Setting policy on the operation of zero occupancy vehicles.
10.	Using pricing to manage achievement of vehicle occupancy targets in on-demand services.
11.	Setting subsidy levels through license fees for on-demand and door to door service.
12.	Encouraging public transport operators to better match demand with micro-transit and robo taxis.
13.	Establishing policies on commercial robo vehicles that manage competition and cooperation with public transit.
14.	Nudging private motor vehicle use by regulating the number of parking spaces in new construction.
15.	Encouraging coordination of private and commercial EV charging at times compatible with optimal loading on the electricity grid management systems.
16.	Ensuring mobility opportunities remain available and affordable for traditional transit customers, older adults, those with disabilities and low-income passengers.

7.2 Harmonization: Mode and Fleet Competition

At present — prior to commercial deployment of road-vehicle automation — motor vehicles and motor fleets of every type, and for both people and goods movement, compete for priority, position, speed, road space and access. Cars compete with transit. Delivery fleets intrude on bicycle lanes. Taxis compete with privately-owned cars. Taxi-brands (as well as TNCs) compete with each other. Some cars — perhaps only a minority — compete with every other vehicle in a zero-sum game: “your journey is in the way of my journey.”

To manage this tragedy of the commons, governments deploy a hefty layer of control systems, signals, highway traffic acts, fines, crash buffers and enforcement officers. While ubiquitous motor vehicle use generates enormous economic and social value, the current operating environment also yields congestion, energy waste, delays, driver stress, transit inefficiency, danger for cyclists and pedestrians, social and political strain, 1.3 million fatalities worldwide and about 200 times as many injuries.

As vehicles are automated and connected, and some of the more aggressive and thoughtless elements of this competition ameliorated, a new form of intelligent fleet and vehicle collaboration will also be enabled. If we do not prepare to manage urban mobility with this new capability, we risk exacerbating traffic congestion, inequitable access, and challenges to urban livability, as opposed to a potential resolution. Private and commercial fleets of automated vehicles could continue to compete in a dysfunctional manner — cherry-picking preferred users, for example — while slowing and complicating the movement of people and goods, including cyclists, and pedestrians. On this point, TNCs such as Uber and Lyft already compete with transit and cycling in many cities. They compete for both participants and space, [Schaller; Clewlow] in the same way that goods delivery, transit, cyclists, and private vehicles compete today and have competed for over a century.

A *safer roadway* is reasonable to expect as fully automated vehicles are introduced and collisions become less frequent, but there is no guarantee of a *more efficient or less congested roadway*, unless these competitive behaviours are channelled and harmonized. Road space demand will tend to increase as urbanization continues and automation makes cheap, personal motor-travel available to more people and for longer distances, unless a shift to shared vehicles is both effective and dramatic. [UITP; CityMobil2] The diffusion of automated vehicles is a complex and uncertain process that will unfold over a few decades. Achieving full penetration of totally automated vehicles is unlikely until well after mid-century.

There is clearly value in a competitive market for mobility. However, if every vehicle or fleet operator plans to use its vehicles to optimize a private or commercial outcome on inevitably limited road space, curb space, and parking capacity, our surface transportation systems will increasingly operate in a hyper-competitive style to our economic and environmental detriment. An example of this problem is the currently ongoing competition between Uber and local taxicab companies. [Schaller] Mobility is a market that needs some rules that yield the safety and knowledge of travel prices that consumers need, albeit with an intelligent, nuanced approach now made feasible by driverless vehicles. A good road network will have operational harmony, while cities and regions require managed competition in the use of road infrastructure. Vehicle automation alone is not enough.

Just as digitization enables automation and connectivity for vehicles as well as MaaS and transit apps for trip management and digital managers for fleet optimization,²⁹ so too digitization can be used to harmonize fleet traffic and preserve the *role* and *value* of public transit within our current road infrastructure by supporting operational efficiency. This is not to say transit itself will not change — it must in order to survive. Rather the solution proposed in the following section and next chapter preserves the social roles and values of transit, albeit without its current artefacts and methods.

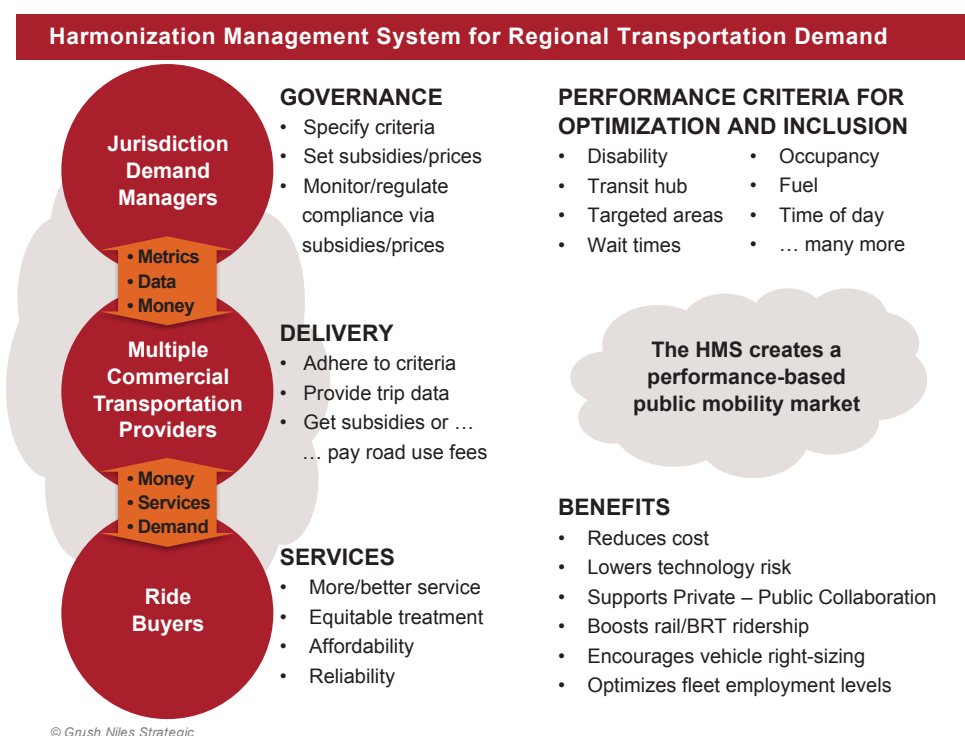
7.3 Harmonization Management System: Solution Overview

The Harmonization Management System (Figure 9) involves three principal roles:

- Jurisdiction demand managers at a selected level(s) of governance.
- Travellers (ride buyer, transit user).
- Transportation service providers (most likely commercial or P3s).

Figure 9: Harmonization Management System for Regional Transportation Demand

Roles, criteria and data flows for a harmonization management system.



A **jurisdiction demand manager** specifies performance criteria and metrics. This entity determines desired performance levels for several optimization and inclusion parameters as well as fees for road use and subsidies for matching or exceeding desired performance metrics. JDMs post jurisdictions' expectations, monitor performance and adjust metrics, fees and subsidies as needed — all via a region-wide cloud-based harmonization management system.

Travellers or ride buyers demand, receive and pay for mobility services. This would include robo-taxis and robo-shuttles (micro-transit). The users should be able to post service opinions (reputation data) that could be included as part of the providers' expected performance criteria. **Commercial transportation providers** register with jurisdictions,³⁰ receive a digital description of the expected performance parameters, subsidies and road use fees and forward aggregate trip records to the jurisdiction demand manager for each trip provided.

A core assumption is that the commercial operation of driverless, electric services on public roads will require a form of licensing and usage charge in lieu of current medallion systems. The harmonization management system described here is not only able to manage usage charges (a road-use fee), but is able to reduce that charge or provide subsidies for exceeding performance levels.

This describes a **performance-based public mobility market** which aims to optimize existing public roads and infrastructure, encourage operators to shape and price profitable services that conform to that optimization and provide the most affordable services to users.

7.4 Harmonization: Performance Feedback System

Without knowing the exact form or predicting the precise timing or diffusion of automotive innovation over the next 20 or 30 years, a system could be constructed now that shapes the performance of these automated fleets to align with the social benefits a jurisdiction seeks.

We are approaching a time in which many — and eventually all — motor vehicles will be fully automated with a significant portion organized into public service fleets for moving goods and people. This means that routes, loads, departure times, sharing, vehicle configuration, fuel types, charging algorithms and many other mobility decisions will increasingly be made either by machine or by algorithms designed for fleet optimization purposes — all likely to be as automated as will the vehicles being managed.

To leverage this opportunity, we propose a harmonization management system (HMS) to connect to all commercial transportation providers and jurisdiction demand managers with an advisory engine whose role is to harmonize manifold fleets as a multi-party cooperation rather than as a zero-sum competition.

A harmonization management system connects all mobility providers and jurisdiction demand managers via an advisory engine whose role is to harmonize manifold fleets as a multi-party cooperation rather than as a zero-sum competition.

An HMS is a transportation management layer that connects to and harmonizes transit managers, MaaS applications, fleet managers, shipping managers, and — eventually — private AVs. It does this without altering vehicles, connectivity systems, fleet managers or MaaS applications. Rather its algorithms exploit artificial intelligence and big data to optimize fleets toward increasing urban and social benefits. HMS performance parameters, road prices and service subsidies are set by regional transportation authorities to influence (nudge) decisions made by fleet managers or MaaS applications. An HMS might not be evident to the individual traveller, in the same way that today's taxi user would not need to be aware of the taxi medallion system.

An HMS influences the flow of these vehicles by calculating performance, prices and subsidies designed to reward trip access and vehicle availability, minimize emissions, foster seamless connections to transit hubs and rail stations, encourage the integrated movement of goods and people such as package delivery using off-peak passenger vehicles, retain jobs, promote ride sharing and vehicle sharing, seek social equity, and nudge vehicle occupancy upward. This suite of traffic demand management controls can be set up according to regional requirements to adjust the performance level of that region's livability, as described below.

An HMS is envisioned as a system of dynamic nudges that vary by jurisdiction rather than a system of rigid mandates. Nudges can be ignored or accepted by fleet operators in ways that best serve their commercial business models. Nudges that may be ignored by some for-profit operators may be an advantage for other operators. For example, available subsidies could support non-profits.³¹ Private fleet operators would remain free to design and establish their services and fees as they please — while having their performance audited within privacy bounds. An HMS is a market-based system. The only difference is that pricing and subsidies turn occupancy, social equity, service design, service reach, ride sharing and other social and operational elements into an effective currency that can be audited and translated into revenue or payments.

7.5 Harmonization: Business Benefits

The business benefits of HMS include:

- Having existing road and parking infrastructure operate more effectively and efficiently.
- Managing the inevitable transformation of much existing public transit into new vehicle types.
- Promoting social equity, access and availability in communities having these values.
- Making fleets more profitable thereby lowering the need for government subsidies.

-
- Helping local business groups — for example, transportation operators who bring people to shopping areas could be rewarded.
 - Nudging some vehicle owners to become ride buyers as service levels for ride-provision improves.
 - Supporting desired changes in parking and rights-of-way that come from a new ownership-sharing mix.

Given the mix of parameter settings, it will be possible to have commercial providers and other ride-vendors offer more services than could municipalities. For example, a for-profit operator could offer a free shopping shuttle paid by retail operators now able to sell or repurpose its parking real estate. The same operators might offer other onboard entertainment services that a municipality could not offer. This approach means government manages social delivery while delegating the management of vehicles, service density, and service offerings to private vendors.³²

7.6 Harmonization: Operation

Core to any HMS would be social governance metrics related to people and goods movement (Figure 9). The settings of these metrics are locally determined for geographic jurisdictions by transportation and transit authorities in conjunction with a pricing/subsidy schema that operate in lieu of a taxi-medallion program, commercial road fees or fuel duties. The HMS layer gathers fleet performance data that is used to determine settlement for prices and subsidies. The usually contentious issue of road pricing is absorbed into the management of massive fleets thereby reducing its effectiveness as a political barrier. [Eno]

Performance targets with their prices and subsidies are set and modified by the regional authority to achieve the effective transportation system it wants. In some regions, targets could be set to ensure revenue from road-use fees for road maintenance. This would tend to pass through as increased user fees or shipping fees set by the fleet operators. In other regions, targets might be set to ensure low per-kilometre costs for lower income travellers or configured in a way that discourages sprawl or promotes transit-oriented development which itself would be influenced by this new technology.³³

By collecting use-data and calculating prices and subsidies, the HMS is managing overall fleet-performance measures. These, in turn, are translated by fleet operators into fleet management and trip service parameters that may include logistical issues like vehicle speed, size, fuel, trip departure, and trip route for both goods and people movement as well as fleet integration, fleet size and fuel types and fuel management. If regional authorities set performance requirements, fleet operators will optimize to maximize profit within those constraints. Besides real-time operating characteristics, this will also influence fleet composition, vehicle size, battery management, service marketing and pricing as well as numerous other factors that control operators' costs and retain profit. Optimizing with regional, social constraints can leave room for profit while reducing the waste spawned by zero-sum competition.

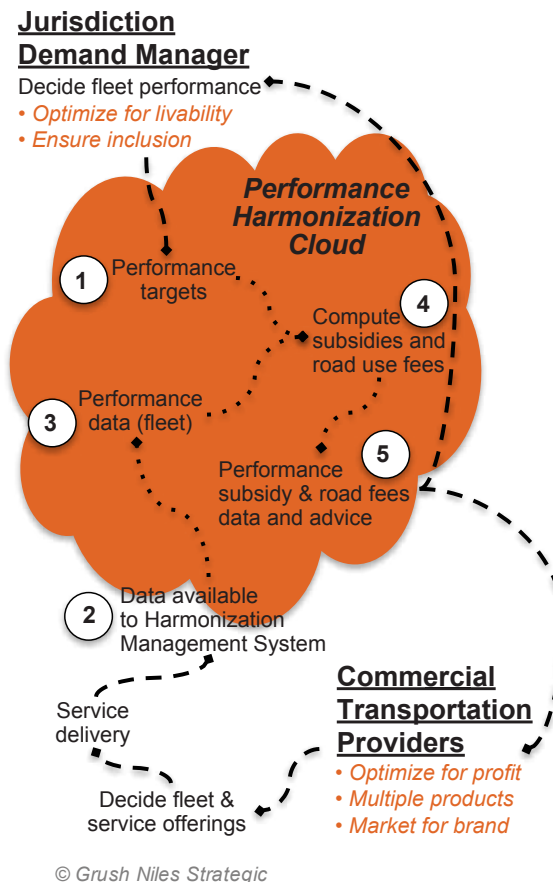
The management of societal, urban, economic and environmental issues is typically of critical concern to transportation and transit authorities. These latter authorities' JDMs would set performance targets for an HMS to manage, and the remaining components of the mobility system would adjust (optimize) to meet these targets. Each HMS should be tuned to regulate a market for the urban performance optimization that the governing jurisdictional authority seeks, while allowing fleet operators to maximize corporate performance within those parameters.

Figure 10 illustrates the data flows in an HMS in a universal cloud management platform whose parametric setup and fleet execution is entirely localized (city, county, district, neighborhood, region). Its big data and AI technologies are universal, but its local transportation management features are re-adjusted as needed by each authority. The following five steps from the figure form the feedback system:

- ❶ Performance targets are set for trip availability, fuel type, vehicle occupancy, vehicles and ride sharing, social equity, aging-in-place, transit connection, access (isochrones) and many other livability and mobility factors that can be served by fleet trip data. These factors consist of target metrics and associated subsidies for over-performing and road-use fees for underperforming. The target rules are scaled and include ceilings and floors, all of which are set by transportation authorities on a regional or sub-regional basis (i.e., arbitrarily granular localization) correlated with standard transportation mapping systems.
- ❷ Data from operating fleets are anonymized, aggregated and made available to an HMS via an Application Program Interface (API).
- ❸ The fleet data are incorporated into the HMS based on local jurisdictions' geography, demographics and regulatory mandate. This is not a one-size-fits-all solution. It can be set or modified as granular as desired.
- ❹ Performance data (big data) and targets are combined to independently weigh each fleet's aggregate impact on each local performance target, enabling a computation of subsidies or road-use fees for each fleet within each jurisdiction. Fleet performance downtown need not have the same targets as uptown or a suburb. This would be monitored and controlled according to mapping information internal to the HMS. *These controls effectively replace the controls a jurisdiction now has when it configures transit routes and frequencies.*
- ❺ The calculated subsidies or road-use fees are settled between each jurisdiction and each fleet operator. Jurisdictions need not be aware of the performance settings of other jurisdictions, although that may sometimes be helpful if adjacent jurisdictions wished to collaborate or better integrate systems.

Figure 10: The Data Flow Between Transportation Provider and a Jurisdiction Demand Manager

The data are used to gauge performance against the jurisdiction's standard intended to shape provider fleet performance and decisions, and to calculate either road-use fees or subsidies accordingly.



The subsidies and fees, as enumerated by the regional HMS act as nudges to each fleet operator to adjust its fleet mix, vehicle size or fuel mix, marketing, routing algorithms, operating times, special-needs passenger programming, pricing for ride-sharing vs. SOV, connections to transit hubs, neighbourhood coverage and any other service component that would reduce its road-user fees and/or increase its subsidy receipts.

A jurisdiction should regulate road-prices, but not ride-prices, as the market under HMS will handle the latter. The right subsidy structure will make it unprofitable to flood a local region with vehicles, as TNCs often do.

7.7 Harmonization: Examples

A simple example is encouraging higher vehicle occupancy: Suppose a fleet operator manages 1,000 AVs in sizes ranging from two-passenger to 12-passenger vehicles in a region where the transportation authority licenses such fleets for use on the local roads for, say, four cents per VKT and with an expected average occupancy performance of two passengers.³⁴ A fleet operator can increase average occupancy by setting its fleet management system to

minimize deadheading, and by devising marketing programs that increase ride-shared VKT (i.e., maximizing the PKT/VKT ratio). A target occupancy level along with a graduated price for dropping below that level and a graduated subsidy for rising above that level can be set by the regional authority and audited by its HMS such that a fee or payment is calculated and settled based on fleet performance.

It would then be possible for an operator to raise average fleet occupancy through various marketing, pricing, vehicle sizing, scheduling and service means to earn a subsidy — i.e., a negative road-use fee — as might occur if the operator ran a minimum-fare micro-transit service in a lower-income area or a preponderance of two-person vehicles with little deadheading. Another operator might offer both high-revenue SOV services to some users and offset those low-occupancy numbers with a lower-cost, high occupancy service for other users.

Other examples include a performance target for the portion of trip origins and destinations that begin or end at transit hubs, the portion of VKT carrying disabled patrons, or the volume of off-peak goods movement in temporarily re-assigned robo-taxis.

8.0 CONCLUSION: THE NEW DIGITAL CONTEXT



This report has taken as its key assumptions that:

- Digital innovation has only just begun its impact on the movement of people and goods.
- This *new mobility* innovation means changes in vehicles, mobility services, modal preferences, emissions, distances travelled, land-use, infrastructure, jobs and employment markets, social equity, health, parking, and dozens of other urban issues and parameters.
- We cannot reliably predict how mobility digitization will unfold or how its multiple facets will interact. We have not determined a way to model and manage these changes.
- Unless there is intervention, the potential costs of this future disruption will be the loss of social equity and a drop in our ability to manage ground transportation for consumer protection and equitable mobility.
- Overall, we remain over-focused on the technology of the automobile, and under-focused on the impending urban and social issues — a veritable repeat of our 1890-1930 mobility innovation era when modern societies replaced horses with cars while having an insufficient understanding and anticipation for pending traffic congestion and air pollution.
- We have a sufficient shared understanding of the technology that allows us to discuss it, but we have a child-like fascination that fuels our descriptions of it. Unfortunately, we have not

been able to dispel our shared wonderment for the numerous and more critical urban and social issues.

- Every gap in the current provision of people and goods movement — and there are many — is a gap that will be locally optimized and exploited for profit; the local focus applies to both geographic and service layers. Without coherent regional or municipal oversight there will be insufficient inducement to the private and civic sectors to provide region-wide or metro-wide service optimization. This could result in mobility deserts where, for example, low-income or physically impaired populations end up with limited options.

This report takes the position that mobility digitization will dramatically affect the ways in which government will be able to provide optimization and inclusion in its role as provider of public transit. As such, our regional and municipal transit authorities must move from an acquire-and-operate mode to one of specify-and-regulate. This is because:

- Technology is now changing too fast for governments to respond; the risk associated with choosing, acquiring and deploying highly automated transportation systems is untenable.
- The cost of new systems, new infrastructure, and attrition of existing systems is out of taxpayer reach without comprehensive design and funding involvement if we are to move dramatically away from unbounded household car ownership and its negative impacts.

Finally, as a designed response to the challenges outlined above, this report describes a harmonization management system (HMS) as a new way to specify and regulate growing fleets toward the ideal of sustainable, optimized performance including social equity that embraces all citizens and visitors. This involves licensing regulated operators to manage fleets under government-selected, user-shaped, social-performance criteria. These fleet operators would be free to innovate vehicles, services and prices subject to safety, privacy and security certification. Beyond performance criteria and certifications, the HMS creates an all-digital market system managed via taxes and subsidies that are based entirely on social performance metrics. This maximizes the social leverage of private innovation, increases regional and municipal governments' regulatory control, and reduces government's investment of tax dollars in owning and operating transportation fleets.

Only digital management can effectively manage mobility digitization.





9.0 APPENDIX: TRANSIT LEAP



The principal solution in the report “Ontario Must Prepare for Vehicle Automation: Automated Vehicles Can Influence Urban Form, Congestion and Infrastructure Delivery” [Grush, 2016] proposed the staged deployment of massive micro-transit and robo-taxi fleets. These would comprise an evolving composition yielding stepwise network expansion starting with localized pockets to culminate in region-wide automation. This report described a way to start immediately and expand in small increments that coalesced into growing contiguous areas so that within 30-35 years the entire GTHA region would be provided with automated public service fleets to a level where a targeted 80% of all PKT would be handled by these fleets and urban rail.

Figure 11: A Summary of Transit Leap

Transit Leap is summarized here paralleling the same four-era temporal framework which was used in the *Preface: A planner's summary*.

Fully automated micro-transit robo-taxi robo-shuttle fixed → on-demand				
Transit Leap	2020s?	2030s?	2040s?	2050s+?
	Early	Rising	Plateau	Mature
Services	 10% PKT in shared vehicles	 25% PKT in shared vehicles	 50% PKT in shared vehicles	 75% PKT in shared vehicles
	Leap 2 5 km ² Managed Area <ul style="list-style-type: none"> • Campus • Small downtown • Protected domain • Neighbourhood 	Leap 3 50 km ² Large Area <ul style="list-style-type: none"> • CBD • Borough • Small city • Transit jurisdiction 	Leap 4 500 km ² City <ul style="list-style-type: none"> • CBD • Borough • Small city • Transit jurisdiction 	Leap 5 5,000 km ² Megaregion <ul style="list-style-type: none"> • Full region • Next region • Service exceeds that of personal vehicle
System	<ul style="list-style-type: none"> • Self-optimizing; flexible • Constrained area • Groomed area • Common service levels • High FTE ratio 	<ul style="list-style-type: none"> • Rich-interconnect to rail • Stronger service levels • Reasonable fleet tailoring • Pick/drop most addresses • Modest FTE ratio 	<ul style="list-style-type: none"> • Any address • Any trip in single vehicle • High fleet tailoring • High social-equity • High service spectrum 	<ul style="list-style-type: none"> • Any time • Anywhere • Any distance • Any weather • Higher service spectrum
Start in constrained areas Grow and merge from local service into megaregion				

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Leap 1 — small isolated pilots, one or two kilometres in radius — is missing from this chart, because these are already underway in some non-Canadian jurisdictions and will be commonplace by the mid-2020s. This sort of early deployment activity is far more important for city building and transit planning than is Ontario's current focus on studying the enabling technologies or solving the snow problem. Companies with a vested interest in such intellectual property will make this investment for our taxpayers. Ontario should ask rather: "How will we use this technology to create the GTHA we want?"

Several Leap 2 projects are already in planning — again, in other countries. Robo-taxi fleets, expected to come on-stream in some jurisdictions in the early 2020s, would be instances of Leap 2 systems. Because Ontario is focused on testing the technology, rather than its deployment, we risk having companies from a non-Ontario or non-Canadian source supply and operate robo-taxi and robo-shuttle systems in our region, just as Uber has done so effectively in the recent past.

10.0 GLOSSARY

Access anxiety: The reason a prospective automobile buyer might avoid purchasing a vehicle unable to reach every reasonably expected destination (range anxiety regarding EVs is one example). Fully automated vehicles (no user controls) that cannot travel to every reasonable destination would have much lower consumer-owner demand than would highly automated vehicles (with optional user controls) that can be driven anywhere.

ACES: Automated, Connected, Electric and Shared. **See CAFI.**

ADAS: Advanced Driver-Assistance Systems.

AI: Artificial Intelligence; computers performing tasks formerly performed only by humans.

API: Application program interface; a set of protocols, formats and data standards to operate between two or more system components.

Automated vs. Autonomous: The expression “Autonomous Vehicle” is not used in this report, except where part of a quote or reference. The word “autonomous” is a common misnomer when applied to the kinds of vehicle robotics we are reporting on. All vehicles envisioned in this report are automated but directed by humans (even when no driver is involved) at least at the highest instructional levels, hence they are not autonomous (i.e., fully self-determining).

Automobility: [1] The use of automobiles as the major means of transportation (*Merriam-Webster*). [2] Use of a powered conveyance under personal control for transportation. [3] This term sometimes encompasses the entire context for the use of automobiles: vehicles, infrastructure, parking, traffic and congestion. Until now, it has been taken for granted that automobility is best accessed by owning a personal vehicle, but with the advent of the automated vehicle, quick-response robo-taxis and robo-shuttles requested using an app may become the dominant form of automobility.

Big Auto: The collective name for the top automobile manufacturers with vehicle models sold in Canada or the United States.

CAFE: Corporate Average Fuel Economy — regulations enacted by the U.S. government to improve the average fuel economy of cars and light trucks produced for sale in the United States.

CAFI: Comfortable, Affordable, Fast, and Instantly available. **See ACES.**

Digital Mobility Governance: Using big data, subscription rules, performance measures and AI to manage a system of multiple fleets of vehicles that have multiple purposes and multiple stakeholders but share public rights-of-way.

Feature-Creep: Ongoing improvements in an industry, like automobiles, that lead to new and compelling features being added as standard characteristics to each model year.

GTHA: Greater Toronto and Hamilton Area.

Harmonization Management System (HMS): A performance-based pricing-and-subsidy system proposed in this report [Ch. 7]; an example of “digital mobility governance.”

ICE: Internal combustion engine.

Inclusion: Social inclusion; the intention of including all segments of an urban population regardless of neighbourhood of residence, employment status, income, age, physical ability, status as a licensed vehicle operator, criminal history, gender, race, religion, sexual preference, health, appearance and so on. One of the two main objectives of public transportation, the other being optimization.

Level 1: The SAE level of automation that provides driver assistance such as acceleration/deceleration or steering systems. **See SAE.**

Level 2: The SAE level of Partial Automation that provides strong driver assistance (ADAS) but requires the driver to be fully attentive and ready to take over immediately. For example, Tesla’s Autopilot at the time of the crash in Florida in May 2016, resulting in a death, was a Level 2 system. (Level 1 and 2 systems are not considered in this RCCAO report.)

Level 3: The SAE level of Conditional Automation wherein if certain conditions prevail the car can operate without human attention, but a passenger must remain in the driver’s seat and be prepared to take over when these conditions no longer prevail. For example, Audi’s A8 Traffic Jam Pilot: “If traffic is travelling at less than 60 kilometres an hour on a multilane highway, and there’s at least one other car on the road, and there’s a barrier between opposite lanes so an oncoming car cannot cross over and crash into you, and there are no pedestrians or traffic lights, then the A8 will do everything, and for as long as the conditions persist.” [Richardson] Barely eligible Level 3 vehicles are becoming available now, and as Level 3 technology matures, the extent of these operating conditions will become considerably more liberal, and it can be expected that Level 3 vehicles will become the personal vehicle of choice during the 2020s. As such, Level 3 vehicles will encourage sprawl, require parking and sustain congestion.

Level 4: The SAE level of High Automation that permits a vehicle to operate without a driver, but in constrained conditions (areas, speeds). These can be considered high-performing, Level 3 vehicles for personal use or, more likely as place-and-speed constrained robo-taxis (regulations permitting). As Level 4 technology matures, their use in providing shared services would likely expand. Many commenters expect that Level 4 technology will be deployed in significant numbers in some locations during the 2020s. The use of these vehicles could disrupt existing taxi, TNCs and bus systems.

Level 5: The SAE level of Full Automation that permits a vehicle to operate driverless, anywhere and at any posted speed. These are not likely to appear, according to the formal SAE definition, until 2050 or later. Many people erroneously refer to Level 4 as Level 5 since Level 4 can be driverless. Often such claimants ignore the stated SAE operating definition to promote a vehicle brand or a consulting service.

MaaS (Mobility as a Service): The integration of various forms of transport services into a single mobility service accessible on demand. The MaaS user accesses these services via a smartphone app.

Mobility Digitization: The use of digital technologies to source, plan and operate trip systems. Three key stages are ride-hailing, MaaS and full vehicle automation. **See New Mobility.**

MoD: Mobility on Demand. See MaaS.

New Mobility is a catchphrase used to describe technologies, often app-centric, that offer a menu of alternatives to the personally owned automobile. These include ride-hailing, car-sharing, ride-sharing, MaaS, multi-modal trips, telecommuting, e-commerce, tele-education, transit finders, integrated electronic fare payment, bike sharing, taxi-apps and, in the near future, automated taxis and shuttles. Related to the concept of the “Mobility Internet,” a new mobility paradigm comprising technologies that create the opportunity to provide better mobility services, more sustainably and at reduced cost: self-driving and driverless vehicles, shared vehicle systems, specific-purpose vehicle designs, advanced propulsion systems and smart infrastructure. [sustainablemobility.ei.columbia.edu] This should also encompass early technologies such as ride-hailing and MaaS. **See Mobility Digitization.**

Nudge: An arrangement in the presentation, framing, description or offer of choices available that alters people’s behaviour in a predictable way without forbidding any options or significantly changing their economic incentives.

Optimization: System optimization; the intention of a service offering such as fixed-route or on-demand transportation where there is continuous management attention to both efficiency and effectiveness of the service. Efficiency is measured in lowered cost per passenger kilometre, and effectiveness by greater quantity and quality of service yielded by the resources dedicated, measured across multiple dimensions. Optimization is one of the two main objectives of public transportation, the other being inclusion.

PAV: Personal Automated Vehicle (including SAE automation levels 3, 4 and 5).

PKT: Passenger Kilometres Travelled (also person kilometres travelled).

Public Transit: Powered mobility that is government provided or regulated in ways that ensure a modicum of publicly accessible transportation for work, shopping or social activities. In this report, public transit can refer to subways, streetcars and buses and can also refer to robotic taxis or shuttles.

P3: Public-private partnership; formal cooperation between government and business to deliver a specific, authorized government activity, facility or system.

RCCAO: Residential and Civil Construction Alliance of Ontario.

SAE: SAE International (formerly the Society of Automotive Engineers).

SAV: Shared Automated Vehicle (including SAE automation levels 4 and 5).

SOV: Single-Occupant Vehicle.

TNC: Transportation Network Company (examples: Uber, Lyft).

Transit Leap: A series of gradual spatial expansions that deploy fully automated vehicles at each stage. Networks of these vehicles grow in capability with technical maturity and spread in geographic range like inkblots as user demand fills in and infrastructure is built until an entire region is automated.

UITP: The International Association of Public Transport (*Union Internationale des Transports Publics*)

USDOT: United States Department of Transportation.

V2I: Vehicle-to-Infrastructure (a form of vehicle connectivity wherein a vehicle may communicate with fixed infrastructure such as traffic signals).

V2V: Vehicle-to-Vehicle (a form of vehicle connectivity wherein a vehicle may communicate with nearby vehicles).

V2X: Vehicle-to-everything (any form of vehicle connectivity: V2I, V2V, V2C [Cloud]).

VKT: Vehicle Kilometres Travelled.

Wicked Problem: A problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements; a problem that resists resolution.

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ENDNOTES

- 1 An early instance of this is the action Innisfil took in 2017 to subsidize TNC and Taxi operators in lieu of introducing a more traditional bus system. [Pelley]
- 2 See Glossary, “Level”
- 3 The authors of the RethinkX report tend to rely on the entire ledger of changes blossoming in exponential technology-time, as though only Moore’s Law were operating, while discounting or ignoring the majority of regulatory, social and installed-base barriers. As an especially egregious example of a fundamental error of extrapolation: “*According to a 2016 NHTSA report, Tesla crash rates decreased by 40% after it introduced its Autopilot capability in 2015. A 40% yearly improvement rate (slightly slower than Moore’s Law) means that AVs will be five times safer than human-driven vehicles by 2020, and 10 times safer by 2022.*” Such statements indicate a complete misunderstanding of innovation diffusion and confuse planners who need reliable projections.
- 4 The first stage of this, Leap1, is being trialled in numerous cities worldwide. It involves automated micro-transit buses on short, slow, fixed routes with human oversight but without drivers.
- 5 Analogous to the expression “from bricks and mortar to e-commerce” used to describe the digitization of the retail industry, so too automobility is moving from “steel and oil” to “e-automobility.” This does not mean vehicles disappear; it means that steel and oil — and especially their personal ownership — will no longer be centre-stage in defining the automotive experience as they are in today’s automobile ads. Instead they will become subservient to the cloud, the way that a taxi serves your trip, then becomes dispensable.
- 6 This would also require the continuation of mostly free roads and underpriced parking that subsidizes current automobile use. Today’s politicians would almost certainly retain these subsidies.
- 7 Land-use planners too often ignore this point, such as when concentrating development in order to make public transit more viable. But good planning practice should not ignore or resist the evident and emerging trends in the economy or in consumer preference.
- 8 Helpfully, both alarming trends have led to an embracement of the promising Swedish concept of Net Zero automobile fatalities, through better roadway design and traffic regulation.
- 9 “Social equity” can refer to a number of things in the context of transportation. In the report, social equity generally refers to access to jobs, shopping or social events within a reasonable wait time and an ability to pay, and regardless of personal physical mobility abilities, race or gender.
- 10 For the future buff who may be reading this: if Ray Kurzweil’s Singularity occurs and or Yuval Harari’s Homo Deus proposal turns out to be true, then the views in this section will have been proven wrong. Until such time, however, these are machines that run on comparatively limited algorithms (compared to people at their best) and need considerable human oversight, whether behind a steering wheel or not.
- 11 This may differ in bike-friendly cities such as Copenhagen and Amsterdam, but the comparison here is among motorized modalities.
- 12 Public transit is not under attack, but the business model of public transit is threatened. [Arbib]
The new mobility players actually see themselves as providing better public transit (as ride-hailers see themselves as providing better taxi service), albeit at a price and in way that leaves some demographics underserved. But the social equity issue is pivotal.
- 13 There is a third and far more insidious problem with the iconic poster comparing of 50 people in one bus or in 50 cars or on 50 bikes. They are not the same people. The people in the bus and those in the cars will differ by trip length, wealth, tolerance, origin-destination, time-value-perception, age, race, gender, physical ability, education, employment, social attitudes, environmental beliefs

and numerous other social features. Mobility management will never be one-size-fits-all, any more than it will ever be my-size-fits-you. That is why that poster is largely ineffective as a change agent — it speaks only to the converted. This is a critical issue for a behavioral economics view when managing massive automated fleets. [Ch. 6 & 7]

- 14 Roughly speaking, in the U.S. and Canada a little over 90 per cent of PKT is currently supplied by personally owned vehicles (“car buyers”), while the remaining percentage is provided by a combination of taxi, transit, TNC and car shares (“ride buyers”). These percentages are broad averages and are not reflective of each country’s largest cities.
- 15 However, the use of automated vehicles to help older citizens age-in-place will become an important focus for moving away from ownership. This is another example of why many different programs and approaches will be needed.
- 16 In the Thatcher / UK privatization of transit, bus routes that were lucrative (volume or affluent markets) saw destructive over-competition from competitive commercial providers, while other less attractive routes were abandoned or subsidized. [Hudson]
- 17 Blair Schlecter is a contributing author to this chapter. He contributed ideas, research and writing on special traveler needs and preferences.
- 18 According to Desrosiers’ May 2017 Automotive report [Desrosiers] the annual YOY rate of new car sales increased in Canada for each of the seven years starting in 2010 has averaged 4.0%, and ranged between 2.1% and 8.2% with 2016 showing the second strongest growth for the period. The same reports show a YOY projected slowing in growth for 2017. Regardless of YOY variability in sales, the total number of cars on Canada’s roads is still growing. A decline in absolute ownership is not evident; to date, any relative slowing in ownership is masked by population growth.
- 19 This is an accurate description of a regular trip made by the principal author for the past several years.
- 20 The word “regional” is used here without formal definition. This is meant to be the wider geographic region embracing the residential, working, shopping, visiting, and recreational area that encompasses the great majority of all trips taken by the majority of its population — i.e., an economic region. In the case of Southern Ontario, the reader can assume the GTHA or even the Golden Horseshoe. Depending on the region one considers, governance might be municipal, regional (e.g., Halton Region, Durham Region or the GTHA) or even provincial, as in the case for Ontario’s Places to Grow, there is the Greater Golden Horseshoe (GGH). If you look at Metrolinx, its heavy rail market is the GTHA, plus Kitchener and Barrie, although GO service is pushing into Niagara Region, for example. This is important because pending technologies will be applied to public transit in ways that obviate municipal boundaries as route constraints for rubber-tired transit. How will cities and towns participate in these new systems that have no geographical constraints?
- 21 Some jurisdictions use coercive systems to reduce driving, such as constraining only odd or even numbered plates on certain days of the week. This has social equity implications in that richer citizens circumvent this constraint by owning multiple cars.
- 22 See footnote 9.
- 23 We assume that while bus systems will be in decline, rail could continue to play critical role, especially if robo-vehicle systems are nudged toward moving a significant portion of ridership to and from transit nodes. We also assume that by 2030 a greater number of subway and GO stations will be in service compared to the combined 135 in service in 2017.
- 24 What is less well understood is the net change as population (and density) rises and per capita vehicle ownership falls. We often look hopefully at relative numbers, when in fact our built

transportation system has certain absolute limits. The assumption that congestion will decline even as the GTHA population grows and car-ownership wanes remains difficult to defend.

- 25 The current aggregate numbers for the U.S. and Canada are closer to seven and nine percent, respectively. These lower averages include rural jurisdictions which are essentially at zero.
- 26 For the mechanics of this proposal to work, an auction is not critical. The purpose of an auction is two-fold: (1) to set a new framework for road-pricing as authorities lose fuel tax revenues from rising vehicle energy efficiency, and (2) to fix in the minds of both operator and traveler that the roads under their vehicles are maintained with a portion of the fares being collected. Operators of automated fleets will be operating (presumably) for-profit fleets on roads already built and historically maintained by taxpayers. Without an auction, governments would still need to set a fee on fleets to replace the fuel tax in the coming years as EVs take a growing role. No matter how fleet road-use is paid for, governments are still left with the issue of user-payment for private vehicles — a problem foreshadowed by today’s politicized road-use-charging debate, although this is made technically easier, and perhaps more palatable, by connected vehicles. Lastly, consider that the fleet franchise proposal in this chapter combines road-fees and transportation subsidies. The allowance for equitable subsidies will yield services that translate into mobility for lower income or disabled users — i.e., subsidizing the ride-buying user, rather than the road-using vehicle. The bundling of road fees net of user subsidies in a fleet’s overall franchise fee permits fleet operators to budget for a wide spectrum of services to reach a greater user population.
- 27 In the same way that retail is moving from “bricks and mortar” to e-commerce, so too automobility is moving from “steel and oil” toward e-automobility. Often the best way to address disruption caused by digitization is with other balancing forms of digitization. It will not be possible to fight the next wave of transportation technology with the plan-and-provide techniques of the past decades.
- 28 According to Goldman Sachs, [Burgstaller, p.14] today’s ride-hailing market is less than 1% of the mobility market and this will increase to between 2.8%-5.5% by 2030. What percentage of that would be ride-shared? Even if we relaxed the definition of ride-sharing to include the 2030 sharing of robo-shuttles that can be expected to replace traditional buses of 2016, what percentage will be as inclined to share rides with strangers in those vehicles as they are in today’s buses that are manned by a driver charged with the security of their persons? We don’t know. All of the non-private PKT today (taxi, bus, car-share, transit) in North America is still under 10% of total PKT. While some of these travelers might switch to robo-vehicles, one can easily imagine that the ride-sharing portion of this new, automated PKT in 2030 might drop.
- 29 Note that the BestMile.com now provides this for massive, automated fleets.
- 30 Preferably through blockchain “smart contracts”
- 31 An example of this would be a non-profit ride-assist program that employs retired people or high school students either on a volunteer or minimum wage basis to accompany/assistant disabled people in automated vehicles. Indeed, such employees or volunteers might earn free trip kilometres to be used later or given to a family member.
- 32 Today’s fleets are Taxis and TNCs. Soon they will be automated electric and shared. As that happens, HMS will become critical to transportation management.
- 33 Responsive, small-vehicle automated transit would tend to extend TOD radii allowing greater populations and greater business variety within a single TOD area. This would increase the ROI and social benefit for each transit hub.
- 34 A high-mileage vehicle would pay more in user fees than would a more specialized, low-mileage vehicle.



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