An Independent Study Commissioned by

RESIDENTIAL AND CIVIL CONSTRUCTION ALLIANCE OF ONTARIO

RCCAO

Constructing Ontario's Future


# Ontario Must Prepare for Vehicle Automation

## Automated vehicles can influence urban form, congestion and infrastructure delivery

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ALLIANCE OF
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**Constructing Ontario's Future**


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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.

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# Ontario Must Prepare for Vehicle Automation

## Automated vehicles can influence urban form, congestion and infrastructure delivery

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 Edgar Baum (contributing author)

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### Author and Acknowledgments

Bern Grush is a Toronto author, speaker and entrepreneur focused on transportation demand management. He is the author of the blogs grushhour.com, which looks at congestion charging and parking pricing, and endofdriving.org, drawing attention to urban and social issues around the deployment of automated vehicles. He is a co-founder of PayBySky.

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# 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). Automated vehicles that cannot travel to every reasonable destination would have much lower consumer-owner demand than would high-performing semi-automated vehicles that can be driven anywhere.

**ADAS:** Advanced driver assistance system

**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] The term "automobility" 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.

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

**Complete Streets:** Streets "designed and operated to enable safe access for all users, including pedestrians, bicyclists, motorists and transit riders of all ages and abilities. Complete Streets make it easy to cross the street, walk to shops, and bicycle to work. They allow buses to run on time and make it safe for people to walk to and from train stations." (SmartGrowthAmerica.org)

**Driver-in:** A car with a driver, i.e., non-automated and semi-automated.

**Driver-out:** A car without a driver, i.e., fully automated.

**ECAN:** Exclusive, Choice, Access, Need (a market development model) (structurally similar to Maslow's hierarchy)

**FDOT:** Florida Department of Transportation

**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.

**FSU:** Florida State University

**GTHA:** Greater Toronto and Hamilton Area

**LRT:** light-rail transit

**MaaS:** Mobility as a Service

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

**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.

**O-D:** Origin-Destination

**P2P:** peer-to-peer carsharing

**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 self-driving cabs or shuttles.

**PKT:** Passenger kilometres travelled (also person kilometres travelled)

**RCCAO:** Residential and Civil Construction Alliance of Ontario

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

**SMP:** Service Model Partnership. A synergistic approach between the private and public sectors to deliver services.

**SOV:** Single-occupant vehicle

**TKM:** Tonne kilometre is a measure of freight carried by a mode of transport

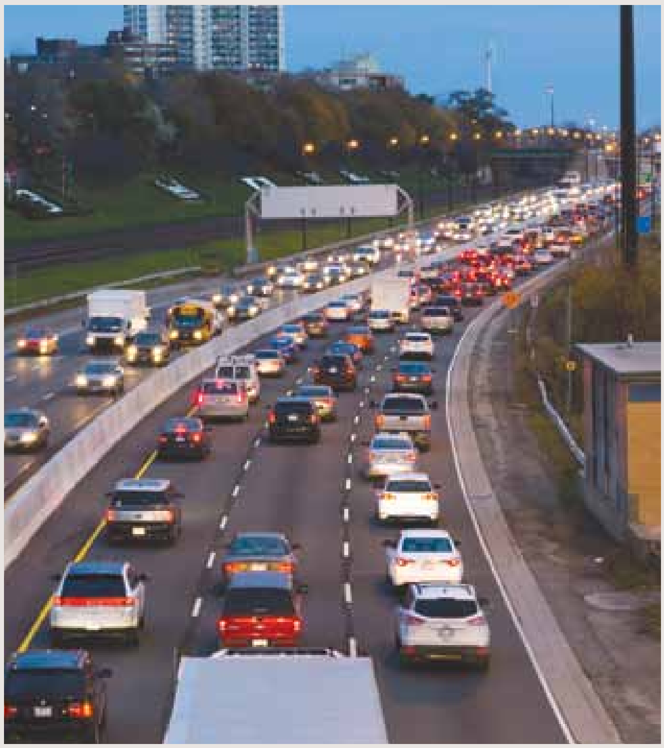
**TNC:** Transportation Network Company (examples: Uber, Lyft)

**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.

**USDOT:** United States Department of Transportation

**VKT:** Vehicle kilometres travelled

# 1.0 EXECUTIVE SUMMARY



Two contradictory stories about our transportation infrastructure are currently in circulation. One is that Ontario's aging, inadequate and congested infrastructure is perennially unable to catch up with a growing and sprawling GTHA. The other is that vehicle automation will soon dramatically multiply current road capacity by enabling narrower lanes, shorter headways and coordinated streams of connected vehicles to pass through intersections without traffic signals to impede flow.

Since the premature forecast of peak car in 2008[1] and now the hype surrounding the automated vehicle, we are often told that we have enough road capacity; that shared robotic taxis will optimize our trips, reduce congestion, and largely eliminate the need for parking. This advice implies we need wait only a few short years to experience relief from our current infrastructure problems given by decades of underinvestment in transportation infrastructure.

This is wishful thinking. Vehicle automation will give rise to two different emerging markets: semi-automated vehicles for household consumption and fully automated vehicles for public service such as robo-taxi and robo-transit. These two vehicle types will develop in parallel to serve different social markets. They will compete for both riders and infrastructure.

The purpose of this report is to look at why and how government agencies and public interest groups can and should influence the preferred types and deployment of automated vehicles and the implication of related factors for planning.

## 1.1 Key Findings

In a market driven by vehicle manufacture and consumption, there will be a race during which the semi-automated vehicle will initially dominate, crowding out the fully automated vehicle as the household vehicle now crowds out all other modes of mobility. The reason for this is that "Access Anxiety" will deny a consumer market to the fully automated vehicle until it can literally operate anywhere without recourse to human intervention, which is not expected until well after 2050.[2] This means:

1. The consumer market from now and possibly until after mid-century will be dominated by semi-automated vehicles implying a driver behind the wheel, thereby constraining the expected spread of vehicle sharing.
2. The business-as-usual success of semi-automated vehicles compared to the full-blown disruption of fully automated vehicles will continue to increase urban traffic congestion and have a negative impact on urban form with sustained or increased parking demand.
3. The fully automated vehicle will be deployed in range-limited robo-taxi and transit applications – and with significant human stewardship – for the first couple of decades.[3]
4. A wide range of vehicles – non-automated, semi-automated and fully automated – will share our roads for an estimated one quadrillion passenger kilometres (worldwide) over approximately three decades complicating our infrastructure management until we are finally left with only fully automated vehicles.
5. In the mid- to longer term, fully automated vehicles (no driver) become the disruptive force that modifies urban form – and in ways still uncertain.
6. The emerging challenge Ontario faces is that the infrastructure needed for the next 20 years may not be the infrastructure needed thereafter.

## 1.2 Market trends and public issues examined

1. The balance between the use of semi-automated and fully automated vehicles; how this will be influenced by technology, regulation,[4] availability and behavioural economics; how will this influence the speed with which we can move through the period of mixed semi- and fully automated vehicles.
2. The impacts of consumer-vehicle automation on public transit; how those can be ameliorated; how transit can stay vital, grow and contribute efficiently.
3. How vehicle ownership can influence the effective outcome of mobility digitization (computerized, on-demand mobility or the Mobility Internet).
4. How broader trends already in progress will interact with vehicle automation deployment.

## 1.3 Recommendations for Ontario

1. Facilitate a public policy debate to allow Ontario to support and encourage a deployment shift to automated, public-service road vehicles as rapidly as applied technology permits.
2. Address governance, infrastructure and programs that promote the widespread urban adoption of shared, fully automated vehicles to reduce the population of personally owned vehicles.
3. Permit household ownership of fully robotic vehicles, but do not subsidize them, except perhaps for specific uses related to special needs travellers.
4. Focus on deployment of publicly available robotic transportation, letting technology companies optimize the technology in response to government or SMP collaboration and leadership.
5. Look to private sector approaches as the best way to manage risk and enable rapid expansion. Allow SMPs sufficient flexibility to reconfigure robotic fleets and re-assign vehicles across jurisdictional and market boundaries for continuous optimization.[5]
6. Recognize that human behaviour and consumer preferences influence modal adoption when designing programs, subsidies and regulations to shift trip-making from personally owned private vehicles to common carrier public-service vehicles such as robo-taxis and robo-shuttles. Include studies to determine how to tailor fleets for wider acceptance[6] – one-size-fits-all public transportation fits very few users.

> "Technology gives us power, but it does not and cannot tell us how to use that power."
>
> — Jonathan Sacks

> "It is only when they go wrong that machines remind you how powerful they are."
>
> — Clive James

# 2.0 A COMMENT ABOUT THE FORECASTS DESCRIBED IN THIS REPORT

I have taken forecast-related information from many sources, and some may appear contradictory. Such apparent contradictions may occur when switching between fundamental forecasts of business-as-usual and the more tentative forecasts describing the use of massive shared robotic fleets – the former taken from projecting current automotive consumption and the latter taken from proposals and simulations and well as some extrapolations from current carsharing studies. I take the former statistics as the more reliable indicators of human consumption, then add to the latter with proposals for shared fleets developed by myself and John Niles.[7]

Vehicle registrations, VKT and PKT are roughly correlated – as are their projected growth curves without automation. These three statistics differ from region to region, having slowed and possibly plateaued in a few developed countries such as Australia, the United Kingdom and the United States[8] (but not yet in Canada). When one considers Table 1, it is easy to see how someone like Bill Ford, speaking at the Milken Global Conference in Los Angeles in 2013, can describe a world of four billion cars by 2050, up from about 1.1 billion when he was speaking, and up from two billion projected for 2030.[9]

**Table 1: Vehicles per 1,000 people by region (U.S. Department of Energy)**[10]

| COUNTRY/REGION | 2003 | 2013 | CHANGE | % CHANGE |
|---|---|---|---|---|
| Africa | 22.6 | 34.6 | 12 | 53.1% |
| Asia, Far East | 45 | 81.9 | 36.9 | 82.0% |
| Asia, Middle East | 85.5 | 129.5 | 44 | 51.5% |
| Brazil | 114.8 | 197.5 | 82.7 | 72.0% |
| Canada | 580 | 646.1 | 66.1 | 11.4% |
| Central & South America | 114.2 | 184.6 | 70.4 | 61.6% |
| China | 18.7 | 88.6 | 69.9 | 373.8% |
| Europe, East | 224.5 | 332.4 | 107.9 | 48.1% |
| Europe, West | 565.7 | 589.6 | 23.9 | 4.2% |
| India | 10.1 | 26.6 | 16.5 | 163.4% |
| Indonesia | 28.1 | 77.2 | 49.1 | 174.7% |
| Pacific | 515.3 | 576.2 | 60.9 | 11.8% |
| United States | 816.1 | 808.6 | -7.5 | -0.9% |

I rely on the vehicle population growth mechanism related to changes in national wealth (GDP) as described so ably by Dargay et al.[11] Table 1 reinforces the efficacy of her model.

I also refer to projections from robo-taxi simulations and some from carshare studies. These extrapolations – often describing 90% reductions in vehicle ownership – are less reliable. Bob Poole makes this clear when he describes problems with the sampling used in carshare studies: too small, geographically constrained, demographically limited, and self-selected.[12] Nonetheless, the media is rife with projections of falling ownership in circumstances for which there is scant evidence on a regional, national or global basis.[13] While vehicle automation is clearly an enabler for vehicle ownership reduction, there is no evidence to support projections that this will happen reliably, quickly, or in the massive waves predicted by some.

The evidence for continued automobile consumption currently outweighs evidence that the world – or Ontario's Greater Toronto and Hamilton Area (GTHA) – will be able to roll this back. The projections John Niles and I use are set to achieve four times 2010 PKT by 2050 with an absolute vehicle population matching that of 2010. These projections are targets rather than predictions.

# 3.0 INTRODUCTION

**We have entered the era of mobility digitization (2010-2035).[14] What digital technologies have done for music, print, broadcast, hotels, entertainment and hundreds of other aspects of human activity, has started to happen to automobiles, trucks and transit. This will influence and be influenced by transportation infrastructure.**

The 2016 RCCAO report "Megatrends: The Impact of Infrastructure on Ontario's and Canada's Future"[15] describes the context of trends that will drive and be driven by mobility digitization. The megatrends described in that report predict the growing influence of mobility digitization, which, in turn, partly contributes to those megatrends. The feedback loops among megatrends, mobility technologies and infrastructure are critical to understanding how infrastructure could influence these changes and be influenced by them. And we need to be looking at the correct trends and looking incisively. "Megatrends act as a wave, that can either swamp you or – if channelled – carry you forward and higher in ways that you could never achieve on your own."[16]

The megatrends may be inexorable, but mobility technologies and infrastructure are malleable. Mobility technologies are responsive to the megatrends and support them. Infrastructure may be less nimble, but it nonetheless enables or prevents mobility change. All three – trends, technologies and infrastructure – are joined in a dance: megatrends are the stage, technologies are the performers and infrastructure is the choreographer. Sadly for the technology (and Ontario's travelling audience!), lousy choreography makes for a poor performance.

## 3.1 Mobility digitization: Progress and uncertainty

The first stage of mobility digitization is represented by "Transportation Network Companies" (TNCs) providing digital aggregation of hundreds of thousands of part-time drivers and their underutilized cars. The second stage, "Mobility as a Service" (MaaS), ups that capability by aggregating all forms of transportation – cars, buses, taxis, subway, streetcars, bicycles, shared cars, motorbikes – into a single app. MaaS provides trip coherence with minimal hassle and without car ownership. And it has already debuted: MaaS Global launched Whim, a MaaS app, in four cities in Scandinavia this year and expects to launch in more cities by year-end. Toronto is under consideration as one of these cities. This is an instance of the "Mobility Internet."

These first two app-based mobility digitization technologies tend to reduce the need for car ownership. Two other digital technologies, virtual reality and telepresence, greatly extend current video-conferencing technologies and tend to reduce the need to travel.

But the most far-reaching of all digital mobility technologies – far greater than all others combined – is "Vehicle Automation." Robotics, far more than an issue of safety and convenience, is a powerful optimizer of time, space, human attention and energy. It is an enabler that will have an effect on human mobility at least as great as the shift from horse to combustion engine. Vehicle robotics will alter fundamentally how, why and how much we travel. Altering how we sprawl, it will tend to flatten our cities.[17]

Some formats of vehicle automation are expected to reduce vehicle ownership while increasing trip counts and trips lengths,[18] while other formats and circumstances will increase the demand for vehicle ownership. This contradiction alone – driven as much by behavioural economics and choice availability as by technology maturity – will cause more uncertainty in planning and infrastructure over the next two decades than any other single factor of mobility digitization.

Vehicle automation is certain to radically transform how people and goods move in Ontario and the world at large. The list of expected changes is long: traffic volume, average speed, travel time reliability, safety, mode mix, congestion, parking, land use, travel cost, emissions, energy consumption, and other environmental and social effects. There will be some we have not yet imagined.

The certainty of change is accompanied by an utter lack of certainty about when and how these changes will occur, in what order and – of paramount concern – in which direction. For example, there are as many warnings of increases in road congestion as there are promises of reduction in congestion, and the vision of vehicles that almost never crash is inconveniently clouded by safety concerns for the decades-long period of time (and approximately a quadrillion[19] vehicle kilometres travelled [VKT] worldwide) in which non-automated, semi-automated and fully automated vehicles will co-exist in formats and systems that are, as yet, undetermined.

This uncertainty means the next few transportation planning cycles will be unlike all earlier long-term planning cycles we have experienced to date.

During these next decades, we can expect that individual travellers will continue to make decisions about trip modality and vehicle ownership as needs arise and circumstances warrant. Such decisions are relatively short term – made for the day or for the few years immediately in front of that individual. These decisions carry small personal risks. Regrets can be undone tomorrow or within a year.

Transportation planners, on the other hand, make decisions dealing with majority behaviours based on a significant number of assumptions about large populations of diverse travellers over large geographic areas decades in advance of those assumptions playing out and often within a governance structure constrained by political interventions unrelated to any of those factors. Regrets cost many billions of dollars and cannot be readily undone.

Mistaken assumptions and subsequent miscalculations imply huge risks that can create over- or under-supply, exacerbate congestion, distort land values and shift tax-bases. Inability to predict the timing and effects of vehicle automation and mobility digitization is now the single most troublesome aspect of regional infrastructure planning – even worse than the staggeringly common complaint of an inadequate funding model.

Systems of moving people and goods involve three major components: vehicles, infrastructure and user demand. Each component comprises innumerable elements. Components and elements interact to influence each other in ways that are increasingly difficult to model and predict. While we see these as complex problems without simple solutions, we look at several factors in support of a bold, pro-active direction for infrastructure planning for the next 40 years.

## 3.2 Report overview

In Section 4: **Why Ontario? Why now?**, we outline the likely effect of mobility digitization on the GTHA in light of three facts: (1) The region is struggling painfully to catch up from a multi-decade deficit in infrastructure development and maintenance; (2) mobility digitization cannot be stopped; and (3) government and mobility digitization are in a race and government is at a disadvantage if it wishes to control the mobility agenda, as it has tried to control it until now.

In Section 5: **Two competing forms of vehicle automation**, we discuss the nature and likely markets for vehicle automation, drawing the conclusion that there are two distinct forms of automation – neither of which is autonomous[20] (see glossary). First brought to general attention by Google in 2015,[21] this market dichotomy is beginning to be more widely understood.

One is the now-familiar semi-automated vehicle, currently mid-development and already available in early formats to provide various levels of Automated Driver Assistance Systems (ADAS), the pinnacle of which is characterized by the Society of Automotive Engineers (SAE) as its Level 3 (see top of Figure 1). The other is the more visionary, fully automated vehicle, also currently mid-development, which in its end-state is SAE Level 5. These two forms of automation[22] do not follow one after the other on social, economic or planning trajectories, as is often implied by the commonly referenced SAE technology trajectory[23] moving from non-automated, through semi-automated to fully automated stages.

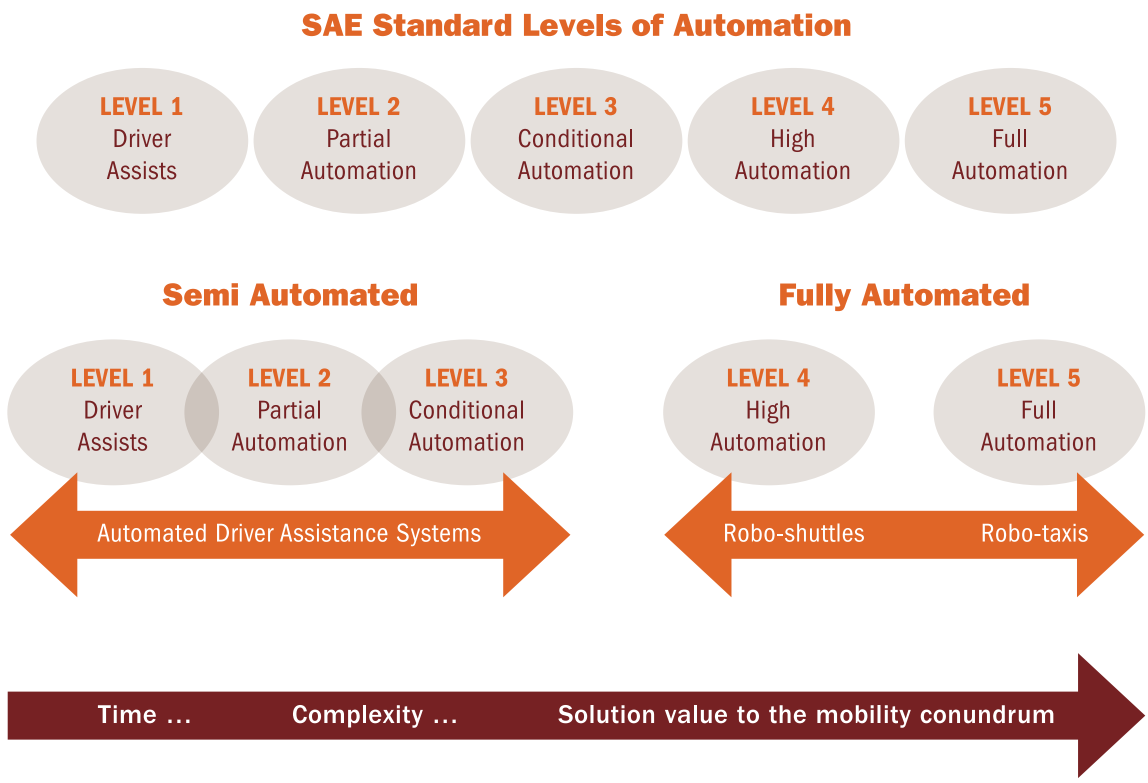
Household ownership of semi-automated vehicles will form the core of the consumer auto market for the decades following 2020.[24] Robo-cabs are projected to handle 27% of worldwide demand for person kilometres travelled by 2030, but because demand growth for motorized PKT during that time is projected to be 35%, the robo-taxi fleet will slow but not reduce congestion. It will make infrastructure issues more complex, however.

Of course, semi- and fully automated vehicles are built on a shared technology base, which is itself currently under development and arguably has an appreciable way to go before any utopian vision of 100% vehicle automation can be realized.[25] In any case, each gives rise to very different markets, use cases and infrastructural demands. We discuss why there will be no significant household market for fully automated vehicles (these are, after all, pubic-service vehicles) and the societal risks of focusing overwhelmingly on semi-automated vehicles, which by design and regulation encourage personal ownership.

We explore the infrastructural implications of each form of automation, recognizing that the two forms will co-exist. The fact that they will co-exist will create a temporary transition state that has complex and troublesome implications for infrastructure planning. To be clear, the fact that they will co-exist is certain; how they will co-exist is not.

**Figure 1: Semi- and fully automated vehicles initially form two competing markets**

Private use and public use, comparable to the household vehicle and transit today. This has started already and may change well after mid-century when the fully automated vehicle is expected to be sufficiently capable to be a household vehicle.[26]



In Section 6: **Transitioning through multiple automated forms**, we look at how the infrastructure-related length and expense of this transition state will almost certainly be exaggerated far beyond one or two normal cycles of vehicle turnover. To do this we introduce a number of ideas dealing with markets, change, and several influential aspects of human behaviour. In this section, we describe why there cannot be a shortcut to the transition to a fully automated vehicle world, and why it cannot be stopped. In other words, this change will occur in spite of its detractors and its current problems, but it will take longer and be more painful due to all of its ancillary systems problems beyond the core technology matters of the vehicles themselves. This additional time and difficulty will have large impacts on infrastructure and its planning.

In Section 7: **How semi-automated vehicles can dominate the next 40 years**, we look at how existing consumer markets and product adoption and ownership rules naturally favour the adoption of semi-automated vehicle ownership over a switch to the use of robo-taxis or robo-shuttles. Our intention is to explore how the powerful effects of marketing, adoption rules and the status quo will tend to lock in a multi-decade preference for high household ownership of personal vehicles (and its attendant infrastructure implications). This section does not comprise a prediction. Rather it is a description of forces that the fully automated vehicle faces on its way to dominance.

In Section 8: **How fully automated vehicles can dominate the next 40 years**, we look at ways to counter the natural bias toward ownership. We examine ways to address and speed up the transition period to full automation. From an infrastructure perspective, we consider how regulation and organization will become more important than asphalt and that the determination of regulations suitable to an intermediate period will be key to minimizing and surviving that period. Infrastructural simplicity and uniformity will be paramount to promoting the transition to automation as the roadways now shared by moving and parked cars, bicycles, pedestrians, delivery vehicles and construction crews differ in layout and markings from one city to the next and even from one neighbourhood to the next in some cities.

From a public transportation perspective, we propose the concept called "Transit Leap," which structurally mimics SAE's well-known five levels of vehicle automation. Transit Leap comprises a series of gradual spatial expansions that deploy fully automated vehicles, initially accompanied by human stewards. 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.

The five SAE automation levels reach market penetration as consumer (household) vehicle acquisition replaces and expands our current fleet; the five Transit Leap levels reach penetration by spatial expansion and service aggregation. SAE automation means more consumption of vehicles, Transit Leap expansion means more efficient use of vehicles. Both mean more PKT. The SAE levels are agnostic regarding ownership. Transit Leap stages are specifically intended for public service and its robo-taxis and robo-shuttles at all five stages would be operated by local government, corporations or through SMPs.

In Section 9: **Viability of Transit Leap**, we look at how Transit Leap stands up to the expected impacts of the megatrends "that will affect infrastructure and infrastructure decisions through to 2030 and beyond." In his recent report focused on infrastructure in Ontario,[27] Michael Fenn explains the "Big Six" megatrends of: (1) Technology; (2) Urbanization and Globalization; (3) Social and Demographic changes; (4) Economic and Workforce changes; (5) Environment and Energy trends; and (6) Political and Fiscal trends. Fenn further outlines 11 impacts of these megatrends to describe the infrastructural world we are moving toward. These impacts effectively shrink distances, times, scales and margins, converge functions, favour customization, reverberate global impacts as local impacts, respond to climate change, alter society's priorities, demand consumer-driven urban design, and mean that "Short-Termism" will threaten progress and sustainability. Any infrastructural ideas or proposals – such as Transit Leap – that reach into this future must either synchronize with these 11 impacts or be stopped by them. Hence, we test Transit Leap against these 11 impacts to argue that Transit Leap is a viable approach for Ontario and its regional governments to take.

We also discuss the deployment viability of Transit Leap: How would such a massive system be delivered? How would social equity be preserved?

In Section 10: **Ownership is more important than the technology**, we discuss how public ownership and management of infrastructure – especially public transit infrastructure – will be disrupted starting now. We are entering an era of increasingly private (corporate) ownership and deployment of transportation vehicles and infrastructure. We can expect growing ridership in vehicles that are not household-owned, but what portion of those vehicles will be subsidized by the public purse and what portion will be managed for private profit – either outright or via co-op, digital-dispatch or SMP structures? How might these changes affect transportation equity and how can that equity be preserved?

A **Conclusion** ends the report.

# 4.0 WHY ONTARIO? WHY NOW?

**Two things differentiate Southern Ontario from many other megaregions: a large infrastructure deficit and automotive manufacturing.**

The GTHA is home to 6.6 million of Ontario's 13.8 million inhabitants. We have grown as or more dramatically than any other region in North America over recent decades.

During these decades of growth, we have lagged badly in our development and management of transportation infrastructure so that we are now blighted with an extreme mismatch between sustainable supply and growing demand. Of course, our well-documented and long-standing deficits in transit, road maintenance, bike lanes and tolled highway lanes are not unique. For decades, large cities throughout the world have been subject to the grinding realities of urban growth, congestion, rising costs and environmental degradation. Perhaps only a minority have fared smarter than most.

While there are many reasons (and debates) why this happened in Ontario, looking forward means that congestion, inadequate public transportation, and the absence of any real handle on the reduction of the carbon costs of transportation firmly grips our region.

We have done a poor job of scaling and maintaining our transportation infrastructure or at least poorer than we might have done had we been able to understand in 1975 or 1995 where we would be in 2015. Even now with $160 billion pledged by the Ontario government to be belatedly poured into transportation infrastructure between 2016 and 2028, we are arguably only barely able to catch up to where we should have been decades earlier.

That we are not the only jurisdiction with this problem does not let Ontario off the hook for the future of our transportation. We need to ask where our infrastructure should be – or, perhaps, wants to be – in 2035 or 2045. To ask that is to ask how automated vehicle technology could influence the infrastructure we need. And to ask that is to ask how we will consume mobility 20 or 30 years from now. Will we consume trips, as promised by advocates of the "sharing economy?" Or will we continue to consume privately owned vehicles, as is projected by a majority of recent polls and market projections? Will we consume more kilometres per person given increased safety and convenience and lowering costs? Sprawl more? Use semi-automated vehicles or fully automated vehicles?

Answers to some of these questions will be biased by current shortfalls in infrastructure and the suitability of infrastructure currently being built. As an example, the proposals, starts and restarts for LRTs and subways in the GTHA are seen and debated through today's commuting lens: traditional buses and bus routes and rail stations competing with the traditional household vehicle. Ignoring our frustrating and cyclic political debates, what other lens can planners use to design toward the uncertain demands, innovation and timing of automated transportation? There haven't been any.

Will transit in Ontario's cities and towns even survive? This is not to ask: "Will there still be 50-passenger buses feeding to and from rail, or lumbering around town on fixed routes and schedules, as now?" Increasingly, people are seeing that the large-format bus of public transit will not survive, much less thrive as many used to assume. Elon Musk puts it this way:

> With the advent of autonomy, it will probably make sense to shrink the size of buses and transition the role of bus driver to that of fleet manager. Traffic congestion would improve due to increased passenger areal density by eliminating the center aisle and putting seats where there are currently entryways, and matching acceleration and braking to other vehicles, thus avoiding the inertial impedance to smooth traffic flow of traditional heavy buses. It would also take people all the way to their destination. Fixed summon buttons at existing bus stops would serve those who don't have a phone. Design accommodates wheelchairs, strollers and bikes.[28]

Rather, we are asking: "Will public transit be replaced – disrupted, if you will – by private transit corporations that can manage swarms of robo-fleets that cross jurisdictional boundaries for origin-to-destination travel as the household vehicle does today?" Or will public transit grow and thrive by using automation to effectively multiply by five- or 10-fold today's transit ridership using the minibuses that are already in trials and pilots in many cities and towns in other countries? Bluntly, will automated vehicles address the "transit problem" in the GTHA by keeping it in the purvey of provincial and regional governments focused on commuting for work and transportation equity? Or will it be privatized in the hands of corporations focused on moving people for profit?

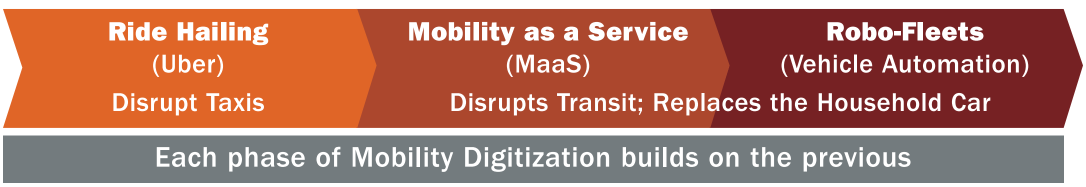
Given the recent 30-year history of digitization, its gathering speed and the fact that mobility is now firmly in its grip, we see growing privatization of public transit services. Programs such as Uberhop and Lyft Line that cherry-pick the underserved fringes of existing transport systems are early warning shots of a battle that bus and streetcar transit premised on late 19th-century system structures can't win. That asks whether privatization will be intentional and regulated, perhaps by working through SMPs and retaining a critical level of governance and control to ensure the mandates of sustainable commuting and transportation equity, or will it be by opportunity and encroachment as TNCs often have shown to be effective in the case of the taxi industry?

We typically think of public transit as a system of vehicles, rights-of-way, transit stops and schedules that are owned by the taxpayer and operated by the government and transit unions, but the ownership and operation of the vehicles is not as important as the frequency and coverage of service, equality of access and affordability for all potential riders.

All regional public transportation – the GTHA's as much as that of any region in the world – is directly in the crosshairs of mobility digitization. This force can be leveraged, ignored or perhaps delayed slightly. But there is far too much money involved to stop it. Private vehicle ownership and transit are both overripe for digital disruption and optimization. Each is wildly inefficient. Each faults the other. Each is part of a critical system with massive revenue streams. The users of each know their current preferred system is flawed, just as all of us came to realize that the taxi industry was flawed only a couple of years ago.

Taxis seemed fine until there was another way. In the face of the first stage of mobility digitization, ride hailing via smartphone became preferable for a significant portion of the taxi-user base and the disruption to the taxi industry was devastating. Just as Uber morphed from an exclusive service for a few to a measurably necessary publicly available service for many, the same will happen in a second and third stage – each one more dramatic than the previous.

**Figure 2: Mobility Digitization comprises three major waves**




The second stage of mobility digitization, MaaS, brings together all means of travel in the form of a mobile app, which combines options from different transport providers into a single mobile service, removing the hassle of planning and one-off payments. Some MaaS packages offer all-you-can-use transportation on a monthly basis at a fixed price.

The third stage will be fleets of robo-taxis and robo-shuttles operating in initially limited areas and ranges over the next decade. These will expand with ever-greater reach, coverage, responsiveness and vehicle types to service all but the most rural areas and unusual needs by the 2040s.

Uber started in 2009 and logged two billion rides by July 18, 2016. MaaS started in 2016 and will hit two billion even more quickly. Robo-shuttles (without rail or guideway but with human stewards) were first showcased in Italy and France in 2014.[29] Robo-taxis (currently experimental and without human operators) are expected to account for 27% of the worldwide PKT by 2030.[30] That 27% extrapolates to 8.5 trillion annual PKT in 2030.

Even if this latter projection is off by a few percentage points or a few years, the numbers are astounding. Worldwide annual automotive PKT, currently estimated at 23 trillion km, is expected to grow 35% by 2030 to 31 trillion km.[31] About 27% of worldwide PKT in robo taxis, given a total of 31 trillion PKT means 8.5 trillion PKT in robo-taxis – almost double the total U.S. PKT in 2015.

An expectation of 27% of PKT in robotic taxis in a system whose demand will increase by 35% means that robotics will not immediately address the current absolute problem, but will only address the relative problem, so that overall demand for infrastructure (both automotive and transit) will still grow,[32] albeit more slowly. There is no evidence that the need for infrastructure will decline in the next few decades. At best, it may stabilize sometime mid-century.

Put another way, the GTHA can expect its equivalent share of robo-taxis by 2030, likely run by private operators or through SMPs. Given Roland-Berger[33] and other projections, this share will mean an increment in VKT beyond our current levels. Given our current infrastructure, congestion is likely to get worse by 2030 in spite of 27% of PKT in robo taxis. At best, the robo-taxis would keep it from getting even worse still.

Only when we reach a far higher portion of trips in robo-taxis and robo-shuttles can we hope to consider optimizing systems of infrastructure, vehicles, trips and congestion. Even then populations, demographics, and wealth distribution will continue to have enormous impacts on vehicle ownership, trip counts, travel distances and the like. Ontario's transportation demands and the systems that sustain it are unlikely to reach stasis in any plannable and fundable future, so that few infrastructure systems being planned will remain suitable for their planned lifecycles.

### 4.1 An elephant in the room

Ontario's major industry is automotive and automotive parts manufacturing. There is naturally and sensibly a provincial focus on assessing the potential opportunity or threat from a disruption by automated vehicles. Will automated vehicles arrive soon? Will Ontario automotive manufacturing and exports make the shift to the new technologies? What happens if the major players change? Will Ford and GM maintain their share of manufacturing whatever is needed?

Clearly a significant change in the volume, type, design and use of vehicles by us or by Ontario's trading partners could trigger enormous threat or opportunity. The Ontario automotive industry is a big ship to turn. This is a critical issue. Economies, jobs, families and communities are at stake.

However important that may be – and it is important – it is only one dimension of what is happening. Automated vehicles of the type that do not require any human operator are an enabler of the endgame of mobility digitization. And mobility digitization can't be stopped.

It is this realization, or certainly something like it, that prompted Ontario's Minister of Transportation, the Hon. Steven Del Duca to "launch a new pilot to allow for the testing of automated vehicles on Ontario roads" in October 2015.[34] As of July 2016, "Del Duca says that there has already been a lot of interest and excitement from both the auto sector and educational research institutions about [automated vehicles], and he expects to see participants in this pilot project in the near future."[35]

The Minister's last statement appears to indicate that there had been no takers to that date. Why were there no signed participants nine months after the announcement of such an exciting program? Because Ontario's focus has been distracted by the technology popularized by Tesla, Volvo and YouTube and many of the glossy consultant reports – that often rely on the assumption we will own automated household vehicles that we can command verbally and take a nap in.

Such automated vehicle technology research is expensive and competitive and the patent space is already crowded. Academic projects are certainly good for training automotive engineers. But none of this would answer the fundamental issue about automotive manufacturing in Ontario. What will be manufactured here in 2021 for household consumption is already projected, designed and planned. The robo-taxis Ford promises for 2021[36] are not for household consumer purchase.

There is more at stake here than just the anticipation of the manufacture and use of automated household vehicles. Governments, manufacturers, and labour unions like stability and growth – or least status quo. Mobility digitization will disturb the status quo. But, if played right, this disturbance can bring new levels of growth and eventually a new stability. And that will not happen automatically. Mobility digitization is as agnostic to Ontario's economy, jobs, families and communities as it is unstoppable.

The single best way to protect a market is to nurture robust sales for that market. If there is to be a market for Ontario-made vehicles in a world with significant numbers of robo-taxis and robo-shuttles – and every indication says there will be – then we should find a way to manufacture some of these in Ontario and use our global experience to export them as well.

A better incentive for Ontario vehicle manufacturers and suppliers would be to contract them to build fleets of fully automated vehicles (starting at Level 4; see Figure 1). There is no doubt that a solution will be found. Ontario firms don't need a license to test automated vehicles. They need a market for these vehicles. And Ontario can provide that – the GTHA alone has 6.6 million potential customers that currently average four person trips per day, most of which are made currently in their 3.46 million cars.[37]

There might be initial objections to such a proposal. One is that the core business model for most non-bus passenger vehicle manufacturers is currently tied to the low cost of capital associated with the securitization of lease/purchase financing arrangements.[38] Any contract to manufacture large fleets of public-service automated vehicles would require an alternate financing arrangement. Any route from a system dominated by household finance-and-ownership to a world of corporate finance-and-ownership would require a new model – perhaps a SMP arrangement incorporating significant private financing from outside of the manufacturing industry. Already many corporations operate publicly shared fleets such as any of numerous carshare operators. This would be similar, but far larger.[39]

While Ford Motor Company promises fully automated vehicles by 2021, Tesla, Daimler and Google have already started to talk about automated shuttles. There are already a half-dozen companies building, slow, safe, neighbourhood-scaled robo-shuttles: 2GetThere, AuroRobotics, EasyMile, Local Motors, Navya, Varden Labs and likely more. One of these, Varden Labs based in Waterloo, is dramatically undercapitalized.[40]

In August 2016, a significant greenfield community, Babcock Ranch – scheduled to grow to 20,000 homes and 50,000 inhabitants – issued an RFI for the creation and operation of a fleet of 400 robotic taxis and shuttles with the stated target of creating a thriving community where the average household light-duty vehicle ownership was 0.4 per capita instead of the current U.S. rate of 0.8 per capita.[41]

In Section 8 of this report, we describe a template for establishing community fleets in Ontario, then growing them to regional fleets, with the express measureable purpose of reducing household vehicle ownership counts. It is contract programs like this that will give Ontario innovators and manufacturers the impetus they need to innovate, hire, manufacture and export (see Section 8.2.3 for an example proposed for a community in Florida).

It is also programs like this that will accelerate the schedule to robo-taxis and robo-transit and start to shift the Ontario appetite for transportation infrastructure away from SOV dominance toward public transportation. The best thing about such programs is their granular scalability and their organic growth that reduces risk as we progress toward this shift. No multi-billion dollar programs need to be paid by taxpayers. No tracks need to be laid.

# 5.0 TWO COMPETING FORMS OF VEHICLE AUTOMATION

**There will be two streams of vehicle automation – one for private consumption, the other for public service. What will that mean for infrastructure planning? How can decisions be made to balance urban-form and financing models even as technology and social change may engender changes in perception and demand for household ownership vs. shared fleets?**

The common thinking about the future of surface transportation has been that automated vehicle technology will evolve through a number of agreed stages along an organized trajectory to an eventual milestone – possibly quite soon – wherein the driver will no longer be needed. Vehicles will keep ferrying people and goods as they do now, but with the driver out – perhaps eventually banned. For persons and families there would be little need or motivation to own a private vehicle. Robo-taxis, robo-shuttles and robo-trucks would do most of the work, and several problems related to safety, congestion, parking, energy, pollution and numerous other current vehicle-related costs would be mitigated. Most appealing for some urbanists and urban planners is the possibility we may need less infrastructure – certainly less new infrastructure.

This simplistic story misleads consumers, misguides planners and is distracting for governance. Politicians can be tempted by its easy promise. The assumption by civic leaders that vehicle automation is the long-sought solution to many or most of the problems we blame on the automobile is to abdicate responsibility.

The automobile as technological artefact is the wrong focus for understanding the larger picture of complex governance of urbanization: planning, infrastructure, city building, and movement of people and goods. Demand for automobility is the more critical issue. We are accustomed to thinking about automobiles. We can see, own, desire or revile them. But it is automobility – how and whether we need mobility, how we consume it, how independent, personal, comfortable and private we demand it to be, how much we demand, and how it is supplied – that matters more. Changing the artefact by automating it does not guarantee that this will show us the way to address the root causes of urban-mobility governance problems given by our various planning focuses on the automobile (or alternate modalities) as currently deployed.

Even while vehicle technology is changing, urbanization continues to generate more congestion. Rising demand for motorized PKT outstrips the unevenly distributed growth in alternatives such as transit and active transportation. Assuming that the coming technologies for automation will finally overcome the problems of the relentless demand for personal motorized travel is risky at best. Depending on how we handle the coming fork in the road to automation, we can easily make some matters worse.

There are two different automotive worlds emerging, one of semi-automated vehicles with a driver required but perhaps often operating in an automatic mode; the other of fully automated vehicles – never with a driver and always in an automated mode.[42] It is natural to assume that fully automated vehicles follow technically from semi-automated vehicles, but full automation will not follow from semi-automation in a social, planning, regulatory, taxation, or infrastructural perspective.

To be clear, the hardware and software components – sensors, maps, intelligence, connectivity, learning and actuators – mean semi- and fully automated vehicles share technology DNA. Just as chimpanzees and homo sapiens share a common ancestry, so too do semi- and fully automated vehicles. These are two technology "species" arising in parallel. The semi-automated vehicle will enjoy market dominance for a few decades, but eventually the fully automated vehicle will come to dominate. This is how we now understand our own evolution – multiple hominem species from a common ancestor with sapiens eventually the sole survivor.

Rather than being a continuum of innovation, the semi- and fully automated species will develop two competing social paths: (1) semi-automated will be a continuation of 20th-century automotive congestion and spatially expansive urban form; and (2) fully automated will be a disruptive force that shifts jobs, alters energy consumption, and modifies urban form – but in ways still uncertain.

Naturally, the matter of infrastructure provision will loom large during the next 40 years. Not only are we unsure what this infrastructure should look like or how much we will need or what it will cost and how it will be funded, we are also uncertain how the two trends – semi- and fully automated – will coexist within any infrastructural regime. What we plan and how we regulate will become far more difficult and far more critical than ever. Given the history of the past three decades in Ontario, collaboration among innovators, planners, and regulators is especially likely to be complex and rancorous – plagued with false starts and non-starts. Collaboration will suffer as regulation lags the technology, planning trails regulations and building stalls as planning hesitates and decisions are reversed. This lag will simply trigger work-around innovations (there is no limit to inventiveness) meaning that regulations, planning and city building will always generate inefficiencies and will be perennially out of date.[43] This cannot be avoided.

## 5.1 Tension between the two streams of vehicle automation

Starting now and for the next 40 years, a new competition between these two kinds of vehicle automation will shape our cities, continuing the century-long trend of motorized transport vehicles shaping urban form.

Initially, semi-automated personal and household vehicles will stay on a business-as-usual path – increasing congestion and sprawl, overwhelming traditional transit, suppressing ride-sharing, competing with cycling, and delaying the release of trillions of dollars in urban real-estate currently occupied by consumer-owned vehicles when not in use.

Lagging this by one or two decades, full automation in the hands of transportation network companies, transit agencies and SMPs could drive down congestion and parking demand by replacing taxis, carshares, rideshares, shuttles and traditional transit with a continuous service spectrum of automated mobility, as mediated by MaaS operators. Depending on regulatory intelligence and foresight, this path will tend to drive up vehicle-sharing, ride-sharing, cycling and walking and release massive amounts of urban real-estate for human use: buildings, parks and active transportation.

What is not known is the relative timing of these two automation streams. Will the semi-automated, personal-vehicle stream swamp the fully automated, public service stream? This would seem likely for the first decade or two if the history of human consumption behaviour has taught us anything. Will full automation eventually dominate? This seems certain at some point. But will it provide sustainable solutions to the problems of motorized automobility and urban form, or just move us to new formats for congestion and another grinding, three decades of plan-and-quarrel for Ontario? Depends.

The doubling time for automotive demand (whether measured in vehicle population or PKT) implies a race between consumer demand and the efficacy of full-automation in driving down congestion – it is easy to predict the mitigation of relative congestion in 20 or 30 years but foolhardy to predict a reduction in absolute congestion. Current consultant projections of automotive utopia for the 2040s are skating to where the vehicle consumption puck was in 2015. The demand problems they promise to solve will likely be far worse by the 2040s. Just as technology accelerates, so do social demands and human consumption.

Many might wish the sentiment at the top of this section, "… competition between these two kinds of vehicle automation will shape our cities," read instead: "… competition between two kinds of vehicle automation will be shaped by local governance." Certainly that would be the hope of the USDOT in its award of the coveted $50 million Smart City grant to Columbus, Ohio, on June 21, 2016. And based on the Ohio capital city's application this award may be headed in that direction – U.S. Sen. Rob Portman, R-Ohio, said: "The grant will help meet the transportation needs of Ohioans who live in the low-income neighbourhoods in and around Columbus to ensure they can get to their job, or receive a good education."[44]

The application of full-automation vehicle technology to goals such as this would imply good governance as compared to simply promoting the development (and manufacture) of self-driving cars by permitting testing on the roads in one's jurisdiction. Jurisdictions that say: "Come test on our roads", are job oriented. And jobs are important. Jurisdictions that say: "How can we deploy this technology to increase transportation equity? To reduce parking demand? To reduce congestion? To increase livability? To clean up our climate act?" are society oriented, and more likely to create an abundance of new jobs given appropriate deployment. It is true that automation needs to be adopted to create this exciting, new market but this adoption needs to be shaped by our social needs to advance motorized mobility in a sensible, new direction. Both approaches shift and change jobs, but the first feels more understandable, more status quo. And it is. And that is its greatest shortcoming and its ultimate risk. Which path will Ontario take?

### 5.1.1 Semi-automated vehicle stream

SAE Level 3 (see Figure 1), semi-automated vehicles will make driving easier, more convenient, more pleasant and more productive during significant portions of trips. By definition, they will require the presence of a licensed driver and they will make these drivers more amenable to longer and/or more frequent journeys.[45] PKT will increase VKT (vehicle kilometres traveled), congestion, demand for parking, distracted driving, sprawl and demand for infrastructure and its maintenance. Drivers of non-automated vehicles will develop an enmity of entitlement toward automated vehicles as some currently have for cyclists. Depending on how they mix with non-automated vehicles, and depending on whether designers can address distracted driving, it is expected that they will reduce accident rates and fatalities. Tellingly, however, insurers remain cautious on this matter, preferring to wait for the accumulation of reliable actuarial data.[46]

Semi-automated vehicle availability for household buyers is imminent (circa 2020).[47] Sales are expected to trend toward a peak in the mid-2030s.[48] However, during the next 20 years, worldwide consumption of motorized VKT is expected to double. Given trends in vehicle sharing and vehicle lifecycle, this doubling may portend slightly less than a match in vehicle manufacturing rates – but without massive sharing rates, the current matter of road and parking congestion will, on the whole, worsen worldwide. In regions of stabilized wealth[49] or population, or hard-won shifts in preferred modalities, road and parking congestion may plateau or dampen. But even with such mitigation, congestion will remain an issue for the foreseeable future.

### 5.1.2 Fully automated vehicle stream

SAE Level 4 and Level 5, fully automated vehicles do not require the presence of a driver, but in many circumstances they will require stewards, cargo assistants or fleet overseers (e.g., by remote video) at least at trip end-points or in particular areas of operation. At first, many vehicles will still command a high human-to-machine ratio, even as a driver per se may not be required. The fully automated vehicle, available at the same time as the semi-automated vehicle, will be suitable, at first, to constrained, well-prepared routes and areas, making it wholly unacceptable for household ownership. Its initial use as a people mover will be in the form of robotic shuttles and then as robotic taxis. Robotic shuttles would likely be subject to more oversight, hence for some time would generate the same level of employment that a normal shuttle vehicle does today.

Fully automated vehicles are fundamentally harder to engineer than semi-automated vehicles. Semi automated vehicles have to be almost perfect in much or most of their range – the driver can be expected to get the vehicle through any tough spots (as long as the vehicle can get a distracted driver to respond appropriately). The fully automated vehicle has to be perfect in all of its range, a feat that can work well enough in constrained areas or on restricted, pre-planned and pre-groomed routes. Not only does this explain why semi-automated vehicles are for household consumption, it relegates fully automated vehicles to geo-fenced or route-constrained public-service functions, at least until their operation is flawless almost everywhere. This also explains why both vehicle classes will see applications at the same time – albeit very different ones – and why the semi-automated vehicle market will peak first and why we will wait for some time until we would consider owning a fully automated vehicle as a household vehicle.

A differential rate of product diffusion – semi-automated peaking long before fully automated[50] – would lead to a period of increasing household vehicle population before finally realizing the impact of full automation and the potential of extensive and flexible robo-fleets to significantly reduce the population of registered household vehicles. The reasons for vehicle population growth in the next one or two decades is developed more extensively in Sections 6 and 7. This initial growth in vehicle population risks increasing demand for yet more household vehicle infrastructure (parking and lanes) for the near term, while further risking that that infrastructure will fall into disuse long before its investment life cycle is recovered.

Sections 8, 9 and 10 describe an approach called Transit Leap that would use full vehicle automation to cap this growth and eventually shrink the population of registered vehicles. An aggressive and early application of this approach would help avoid a temporary and unnecessary final investment in road and parking infrastructure intended for personally owned vehicles.

# 6.0 TRANSITIONING THROUGH MULTIPLE AUTOMATED FORMS

**How Ontarians might respond to changes in automated vehicle levels; natural inhibitors to the uptake of full automation; why semi-automated vehicles will peak long before automated vehicles will.**

Most observers believe the developed world is on the cusp of a tsunami of automotive innovation. Most also believe that this could enable a miraculous relief from our transportation woes, or conversely, trigger a terrible exacerbation of these problems.

Given the unprecedented combination of certainty and uncertainty, infrastructure planning is at a new kind of compound disadvantage. This uncertainty means planning for the next few decades with a backdrop of impending vehicle automation will be wholly unlike any other multi-year transportation planning exercise we have experienced. Many may agree on the nature of a few of the disruptions that will accompany this technology, but for most of the robotic future, there is only uncertainty.

For this reason, one critical focus of this report is the issue of coping with two competing streams of vehicle automation. While we can be certain of someday not needing a human operator for nearly all vehicles in most circumstances – i.e., pervasive vehicle automation – we can be even more certain that there will be an extended (multi-decade) length of time wherein a significant portion of travellers will ride in semi-automated vehicles, while a lesser and eventually growing number will travel in fully automated vehicles.

This changeover period will be both complex and complicated.[51] It will also be troublesome for strategic infrastructure delivery.

## 6.1 Predicting vs. Hoping

Collectively, we entertain contradictory predictions about vehicle automation as given to us through various biases: car manufacturers promote exciting consumer brands; transportation professors solve robo-taxi simulations which are then extrapolated to show the decimation of car ownership;[52,53] safety engineers advance the life-saving value of artificial intelligence informed by sensors; journalists are awed by what they see at a trade show.

Taken together, this leaves those charged with deliberating Ontario's path for a regional municipal transportation plan with more questions than answers.

**How soon will full automation become mainstream?** Nobody can ascertain the time of arrival of full automation – i.e., consistent and pervasive in a region or city, and not just Ford's or Uber's first release. We can easily imagine technical feasibility in most operating circumstances, but we cannot say when sufficient reliability will be exhibited in every circumstance – indeed, some credible analysts express doubts this will happen for several decades. That means we don't know when (or if) any different sorts or scales of infrastructure will be needed, or how long what we contemplate building in the interim will be needed. We are at risk that technology and demand will change more rapidly than government can respond – indeed, many believe that this has long been evident.

**Will automation mean more or fewer vehicle kilometres travelled?** Currently, humans are capped out at a worldwide average of about one travel-hour per day. If we can eat, play, sleep, read, work and shop instead of attending to driving, how much further will we sprawl? Recent evidence is equivocal. Many people who cannot drive now forgo trips or have chauffeurs or use transit sometimes begrudgingly. Non-drivers with new freedom of mobility are expected to add to PKT in personal automated vehicles. Will this also increase the number of privately owned vehicles? Or will high robo-taxi availability suppress ownership? Will more automation mean more ride-sharing as some assert?

**Will automation make travel cheaper?** Humans now spend an average of 13% of their income on travel.[54] Automation is expected to eventually lower the cost of the vehicle and its fuel, insurance and parking fees. When something is cheaper, more is consumed. Will the travel savings be spent on more or longer trips as projected by several studies? Or on bigger vehicles as is common in North America now? One might think rational travellers would spend the windfall travel budget elsewhere – say on education, housing or earlier retirement, but that has not been common behaviour for many of us. Trips represent considerable value for travellers.

**Will new automotive players change the landscape of solutions?** Will incumbent automotive manufacturers stage innovations to sell more semi-automated vehicles and very appealing safety features for more model years, or will new full-automation players like Easy Mile, Google, Navya and Uber steal the puck? Both types of players want to sell more. The incumbents sell vehicles. The new players sell trips. And some of the incumbents such as BMW (Car2Go) and Daimler (ReachNow) have already started selling trips as well. Many others are planning to do so (see Musk's comment in Section 4). However you slice it, there would be more vehicle kilometres travelled.

**In what order will automated vehicle solutions be applied?** Will we automate transit or goods logistics first? Expecting both to happen all at once – say over a decade – may be physically, operationally and socially impractical. Or will governments set regulations and let automotive manufacturers sell what they might to household consumers, while letting the insurance companies and logistics operators work out the issues of mixed, driver-in and driver-out, traffic?

**Will shared fleets or household vehicles dominate?** Critically, the jury is out on the matter of vehicle ownership, even though hope-filled forecasts paint a picture of inevitable, widespread vehicle sharing. Roland Berger's "(R)evolution of the automotive ecosystem" predicts that 27% of all PKT, worldwide by 2030 will be in robo-taxis – spatially constrained but fully automated vehicles. While this percentage shift is possible from a manufacturing perspective given sufficient advances in technology and re-tooling to produce some 75 million vehicles – the approximate number needed to service the 8.5 trillion PKT implied in the Roland Berger report[55] – it seems socially and structurally unlikely to happen this quickly in North America. The infrastructural, regulatory and logistics picture is daunting.

The point here is not to suspect Roland Berger's 27% figure. It is a defensible estimate. Perhaps its 2030 timing may be five years early for a jurisdiction such as Ontario, and likely these numbers will be realized more quickly in some developing areas of the world. As often happens, technology is adopted sooner where there is not an extensive sunk investment in an earlier generation of technology.[56] Of course, the other half-expected outcome is that a handful of auto-tech companies will finance, build and operate these fleets. When that happens, will the infrastructural, regulatory and logistics matters have been sufficiently considered so that Ontario can leverage this new market – both for its automotive industry and its travelling population? Should the province be focused on encouraging technology testing and resting on the laurels of the forward-thinking mayor of Stratford for permitting testing in his city,[57] or rather on the far more complex infrastructural, social and financial context of deployment of a robo-fleet that handles 27% of all PKT within 15 years?

**Will the advantages of shared fleets be available to most urban travellers?** Will these advantages be both evident to, and selected by, the great majority of travellers so that household vehicle populations shrink dramatically? Will the car become more of a travel service and less of an accessory – i.e., all about the trip, nothing about status and private mobility? Many academics assert that "few people will own fully automated vehicles; most will share them,"[58] but there are many reasons – rational or otherwise – that most people currently prefer ownership, even while a growing few have found ways to avoid owning a vehicle. Rational economic notions of sharing can easily be defeated in the context of culture, habit, status, privacy, hygiene and convenience. Automobile marketers have learned to do this very persuasively. While it is too soon for certainty whether consumption or conservation will dominate, history has preferred consumption.

## 6.2 Access Anxiety

Will fully automated vehicles really be purchased as family vehicles? As described in more detail in section 5, there are two forms of vehicle automation: semi-automation (we already have this in many vehicles and for which we will see rapid, ongoing improvement,) and completely driverless automation (as promised by efforts such as Google's or Uber's). These are generally described in an evolutionary continuum (see Figure 1) wherein semi-automated vehicles keep improving until they no longer have steering wheels – just as humans no longer have tails.

But there is a break between semi-automation and full automation, like the one between reptiles and mammals. Evolution becomes revolution. Evolution demands drivers stay in the vehicle, but they need hardly attend to the task; they will gradually fall away. Revolution will result in no driver at all.

Imagine being given a showroom choice in 2026 between a superb, semi-automated vehicle that can drive from any address in London, Ont., to any address in Pickering in all but the worst weather, with little need to touch the controls; and a fully automated vehicle that promises to do the same, but provides no way for you to take over in extreme weather or on the unmapped dirt road to your friend's cottage north of Muskoka or into a small town that no longer permits fully automated vehicles since a fatality involving a failure of one of these vehicles two years earlier.

Few consumers would purchase a vehicle that can go most, but not all places. Such "Access Anxiety" parallels "Range Anxiety" that has so effectively dampened electric vehicle sales until now. It is likely that there would be only a very small and specialized household market for fully automated vehicles for 40 or 50 years. Consumers of automation will always prefer the ability to drive, especially if they wish the freedom to access anywhere and everywhere in any circumstance. A fully automated vehicle that provides a 100% level of access without human intervention is considered by some experts to be available only after 2070.[59] In the long interim, semi-automated vehicles will sell very well to households, and such sales would put us at risk of more congestion, more demand for lanes and parking, and more outward urban growth in the several decades preceding full, no-driver automation.

Can we create immediate and better transportation alternatives to mitigate this threat?

## 6.3 Utopia Simulated

Simulation-based research has been generated for hypothetical deployments of robo-taxis in Austin, Tex., Lisbon, Manhattan, Stockholm and other cities. Consistently, researchers report that each simulated robo-taxi can replace about 10 family-owned vehicles. The simulations appear realistic in that they have been parameterized using the origin-destination (O-D) data collected in their respective cities but, in most cases, the researchers suggest – and reviewers conclude – that the computed outcomes can be extrapolated to the world vehicle population. As illustrated by Ronald Bailey in "The End of Doom":

> Researchers at the University of Texas, devising a realistic simulation of vehicle use in [Austin] that took into account issues like congestion and rush-hour usage, found that each shared autonomous vehicle could replace 11 conventional vehicles. Notionally then, it would take only about 800 million vehicles to supply all the transportation services for nine billion people. That figure is 200 million vehicles fewer than the current world fleet of one billion automobiles.
>
> In the Texas simulations, riders waited an average of 18 seconds for a driverless vehicle … and each vehicle served 31 to 41 travellers per day. Less than half of one percent [sic] of travellers waited more than five minutes for a vehicle. In addition, shared autonomous vehicles would also cut an individual's average cost of travel by as much as 75 percent [sic] in comparison to conventional driver-owned vehicles. This could actually lead to the contraction of the world's vehicle fleet as more people forgo the costs and hassles of ownership.[60]

There are several problems with these best-case simulations and the conclusions drawn from them. These studies, while constrained by the use of pertinent O-D data, encourage unwarranted generalizations that cannot be reasonably extrapolated to suburbs and rural areas or work/service-related vehicles. Projections such as echoed by Bailey must assume an inevitable and general willingness of all or most travellers to use shared vehicles. There is much good to be said for vehicle sharing, but there is no evidence that all or most Ontarians will engage this way. Indeed, there are many barriers to such a general outcome.

## 6.4 Moving from non-automated to semi-automated to fully automated

We see fully automated vehicles in the long run increasing shared vehicle use, reducing demand for parking and easing congestion. This is changing the nature of infrastructure provision but in ways that are not yet clear. Semi-automated and fully automated VKT will peak at different times: semi-automated will likely peak two decades earlier.[61] This has powerful implications as we go through a period of time where our household cars cause ever-greater problems until automation fully matures. The change from all horse-drawn vehicles to no horse-drawn vehicles took 40 years. We can expect a similar trajectory for the transition from no automation to full automation – 2015-2055 – if not longer.[62]

Semi-automated vehicles are imminent. Consumer uptake will occur in the next couple of years and sales will be in full swing during the 2020s. Fully automated vehicles will have no appreciable sales to private household consumers for at least two decades and as many as four decades due to Access Anxiety (Section 6.2) and lack of appropriate, uniform and comprehensive regulation. During these decades, fully automated technology will be used for special purpose and public-service vehicles: robo-taxi and robo-transit. The nature of semi-automated vehicles – making driving more attractive, relieving some of the occupants' pain from congestion, increasing safety for its passengers, and restoring the convenience of driving a family-owned vehicle – coupled with its immediate availability within three or four years vs. the nature of fully automated vehicles – constrained locations and uses, slower travel, shared rides, public transit focus and a much longer wait until availability – means that PKT in semi-automated, privately owned vehicles will immediately, and for a considerable time period, far out-number PKT in fully automated shared vehicles. What is predictable is that the public-sector effort and SMP collaboration necessary to make fully automated PKT a dominant component in intra- and inter-urban mobility will take far longer to regulate, plan and mobilize than it will take automakers to stock showrooms with desirable, understandable and affordable semi-automated vehicles.

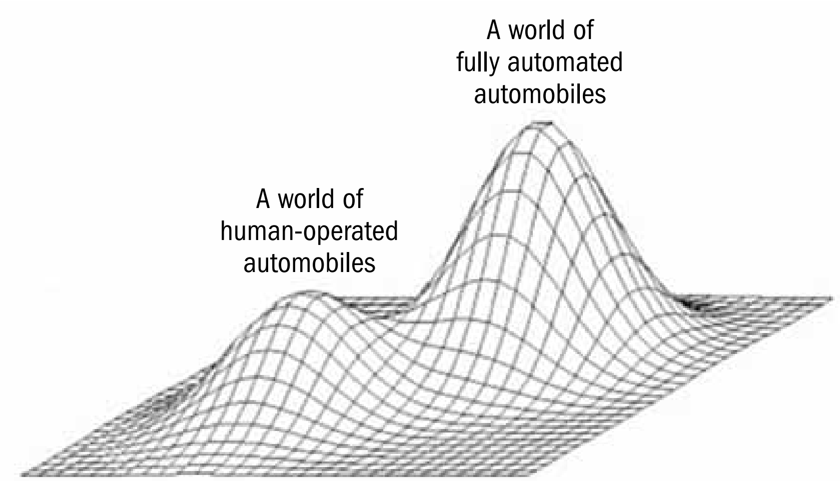
The current 20th-century system of automobility, with its drivers and its faults is arguably a system that serves many valuable purposes. Many portray the imagined system for mid-21st-century automobility – safe, clean, instantly available robo-taxis – as an improvement over the current system.

Any effort to move from one system to another, from one situation to another or from one method to another implies a cost. That cost or pain is represented in Figure 3 as the dip between two local optima. The relative dip between any two such solutions is often deeper than expected. Such will be the case as we shift to automated vehicles.[63]

One of the common features of moving from one system, circumstance or method to another is that we are often moving by trial and error. We might not have a road map, as it were. The optimal route in the illustration (Figure 3) would be along the ridge or saddle between the two peaks. But there is no way for us to know with certainty where that saddle is. So the likelihood is that we will take a highly sub-optimal route to the desired new state. This will be the case as we move from non-automated to fully automated vehicles. It is impossible to guarantee that we can reach the optimal state much less that we will find a tolerable path to it. The even bigger question is how can we avoid getting stuck in the saddle, as we arguably have been stuck during the migration from horses to cars (Section 10.1).

**Figure 3: Moving from non-automated to fully automated**

Many assume that a world of fully automated automobiles is a better place, but how we traverse from human-operated to fully automated will not likely be so easy.




Critically, a dip is unavoidable when moving between two optimal states. The improvement is not 100% efficient; it is an evolution that requires the mutual acceptance and enablement of going through the saddle with as little pain as possible. That requires going in with eyes open and acknowledging that the dip will be experienced and taking responsibility for that as makers, planners and union leaders.

There is also a multi-generational attachment to past comforts. It's what people grew up with, making this as much about psychology and behavioural economics as it is about technology. Will infrastructure influence or exacerbate the tension between behaviour and technology? Ontario's current infrastructure deficit certainly does.

What's worse than what is illustrated in Figure 3 is the dawning realization, as this report underscores, that we need to either pass through two saddles (non-automated to semi-automated, then semi-automated to fully automated) or pass through an even deeper saddle to move from non-automated to fully automated. Either way, as Ontario moves through this process, robust solutions to the 40-year infrastructure puzzle are not evident.

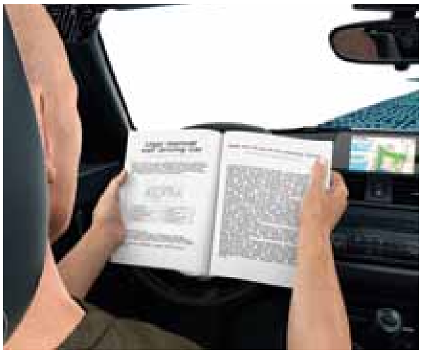
It's one thing to imagine life while watching a science fiction movie with robotic vehicles embedded in the storyline. It's another matter now without us yet having futuristic dystopias on the bridge between semi-automated and fully automated. It's not in the public imagination. We must also acknowledge the risk of NIMBYism and the power of nostalgia for how things used to be. Humans are patterned to this behaviour.

The immediate and relative familiarity of the semi-automated experience for the great majority who currently own and use household vehicles means a low personal/cognitive transition cost relative to switching to fully automated public vehicle use. By transition cost, we include financial, social, schedule habits, dress and packing habits for travel, how our kids are chauffeured and monitored, and numerous other elements of using an owned vehicle that may hover above or below conscious awareness. The transition will be easier for people who do not own a vehicle and do not have easy access to a family-owned vehicle, but far more difficult for person or family that is habituated to owning one or more vehicles.

It is also important to emphasize that the capital cost of vehicles – regardless of the level of automation – is an impediment to rapid adoption of even semi-automated vehicles – a stage that the developed world will not be able to avoid completely. A car is much more expensive than a mobile phone and its minimum cost is still substantially higher than that for a cell phone. The Tata Nano, purely for getting from point A to B, costs $3,000 in India. That is still the equivalent of $20,000 for someone in North America in terms of market tolerance for purchasing a vehicle. What we expect for $20,000 in North America is constantly becoming more sophisticated and demanding.

These considerations will slow the dual phases of change from non-automated to semi-automated to fully automated, effectively delaying a change to the shared-vehicle world predicted by many hoping for a world in which the appeal of vehicle ownership would rapidly plummet toward zero.

# 7.0 HOW SEMI-AUTOMATED VEHICLES CAN DOMINATE THE NEXT 40 YEARS

**No matter how much we hope or expect motor vehicle ownership to decline in 20 or 30 years, markets have consumer adoption rules that must be respected. Using a market dissemination model called ECAN, we explore what will make the existing market model for household vehicle preference transfer to the semi-automated vehicle and continue to lock in an overwhelming preference for high household ownership of personal vehicles.**

## 7.1 Markets: technology adoption and stickiness

All of this thinking and divining about the value of vehicle automation depends on a massive change – or not – in the fundamental market(s) for automobility. Will automation replace non-automation? Will fully automated vehicles outsell semi-automated vehicles? Will we consume trips or vehicles? Which technology gets adopted, how quickly, and whether it sticks, may be all that matters to the question of how we should think about infrastructure. Unfortunately, we are given two equally assured but opposite answers: (1) we will mostly consume vehicles; or (2) we will mostly consume trips.

A resolution to this simple dichotomy is not obvious. Lindsay Stevens, Jeremy Cruet and Jordan Crandall of the Florida State University (FSU) in collaboration with the Florida Department of Transportation (FDOT) presented "Envisioning the City with Automated Vehicles" in April 2016 at the APA's National Planning Conference in Phoenix.[64] In a wide-ranging summary of the current state of thinking and expectations and a listing of many of the commonly espoused benefits of automated vehicles, they offered a remarkable projection:

> By 2040, there will be a 50% penetration of automated vehicles of which 90% will be privately owned and 10% would be shared; and by 2060, there will be a 100% penetration of automated vehicles of which 70% will be privately owned and 30% would be shared.

On first considering the Stevens et al. world of 2060, this appears to be a somewhat better world than now. Since per capita vehicle ownership in the U.S. is currently at about 0.85, and shared-use barely registers as a statistic, 30% shared-use 44 years from today sounds miraculous to 2016 ears. Unfortunately, there is no acknowledgement of normal organic growth in demand for motorized transportation (worldwide, demand doubles every 20 years, although likely this will be less aggressive in Florida, since the U.S. is closer to demand saturation).[65] The FSU projections regarding a relative 70% in private ownership in 2060 masks the interpretation that, all else equal, congestion would actually get worse by then since absolute mobility demand will have increased far more than would be mitigated by such a relatively modest drop in vehicle ownership rate.[66] As well, these academics are relying on ideal, highly connected, accident-free, smaller vehicles, travelling closer together, in narrower lanes, through non-stop, non-signalized intersections – all of which, unfortunately, are assumptions without standards, regulations or a detailed, evidenced-based understanding of their infrastructure requirements.

In order to make all of these things come together for 2040 or 2060 and work within a region the size of the GTHA (much less across Canada or North America), the level of collaboration, systems coordination, market standardization – including vehicle communication, automated behaviour rules, and vehicle sizing (how will narrow lanes handle both F150s and Smart ForTwos?) has to be at a level far beyond anything seen in the planning for D-Day, the Manhattan Project or the moon landing. Remember how long it took to have Microsoft Word files produce matching results on PCs and Macs? We will need to run a multi-trillion dollar surface transportation system – one that currently kills 40,000 people annually in North America – with narrow lanes and non-signalized intersections[67] comprised of hundreds of makers and thousands of planners far better than we managed with printer fonts for more than 30 years.[68]

If we are going to consume mostly vehicles as opposed to consume mostly trips, automation will make little sustainable difference. The automated vehicle halo effect currently in vogue will not survive.[69]

This type of thinking is optimistic as it focuses on the potential of technical componentry which we have always found much easier to contemplate than the realities of logistics, coordination, infrastructure, funding, and human behavioural change.[70] From a systems perspective, it focuses too closely on technology innovation and its immediate properties and too little on its deployment context and its secondary and tertiary effects and influences. We seldom distinguish what could happen from what needs to happen to make what could happen, actually happen. Most thinking is hopeful, incremental and "business as usual" – the major difference being that the driver need not hold a steering wheel, a relatively trivial idea that currently grips our imagination.[71] The FSU 70% ownership projection for 2060, means there will still be a vehicle parked in a great majority of Floridian driveways and presumably still idle 95% of the time. Since the 70% vehicle ownership of 2060 means more rather than fewer total vehicles compared to the 90% ownership of 2040, the FSU study authors are inadvertently projecting a worsening problem and a demand for more infrastructure – narrower lanes aside – while likely not appreciating that they have done so since they focus on percentage improvements.[72]

If the FSU/FDOT projections were to be right, would outcomes in Ontario be as good? After all, Florida – with a population 46% larger than Ontario's – has learned how to toll 2,800% more kilometres of its highways than has Ontario – 1,200 vs. 42. If this comparison is indicative of Ontario's comparable will to address its surface transportation deficit, automated vehicle deployment metrics in Ontario in 2040 would fare even worse than it is projected to fare in Florida.

The disruption that vehicle automation makes available may be different than FSU projects or perhaps another sort of disruption will be forced upon us. But neither is imagined in these FSU projections. In the end, what will determine the disruption that actually does take place? Automotive marketing? Government regulation? Government investment? A new worsening of the state of our infrastructure? The influence of digitization, especially mobility digitization, on our preference for owning/driving or sharing/riding? A long-stagnant economy that puts vehicle ownership out of reach for a growing portion of our population?

## 7.2 ECAN

**ECAN is a market penetration and dissemination model we will use to describe how the automobile – among many other innovations – has come to be seen as an essential need for most people and families in North America. We argue that this model, by default, will favour household ownership of semi-automated vehicles over the use of shared public service vehicles. We assert that the replacement of vehicle ownership with a market for trip consumption would need to leverage this same model in order for shared vehicles to become the dominant mode.**[73]

In general, innovations begin life in the market as **Exclusive** or unique. Many automotive features began this way. Horns and headlamps in the beginning, windshield wipers later, then power windows and anti-lock brakes, and now high-end cruise control such as the misnamed "autopilot" from Tesla. Expensive at first, these innovations find their way into an increasing number of products – or models in the case of automobiles. This leads to growing **Choice** and consumer selection, until the innovation boasts wide affordability and distribution leading to general **Access**. Such innovations finally become standard and expected. Buyers **Need** them. No one would consider a car without windshield wipers, even if one were offered. Few would buy one without power windows. ABS are now standard.

**Figure 4:** **The ECAN model**

The ECAN model represents the pathway of how perceptions of key, differentiable tiers of engagement with a solution (whether product or service) drives changes in behaviour, and critically, new perceptions for the future in the same class of solutions. ECAN models are, by their very nature, not static, as there is constant competition to differentiate within each of the four tiers of perception.

| E | C | A | N |
|---|---|---|---|
| **Exclusivity/ Uniqueness** | **Choice/ Selection** | **Access/ Distribution** | **Need/ Necessity** |
| **Limited/early access; self-identifying qualities; status buyers; special niches** | **Fast followers and mass affluent seek affordable choices; sales to upper middle class and niches** | **Market expects ability to buy; companies incentivized to mass produce; prices drop** | **Sustained reason or fundamental basis for the existence of the category** |
| **Smartphones:** initially launched with limited niche access; e.g., original Blackberry, first iPhone. | **Smartphones:** new manufacturers; smart-phones for the masses; still above average budget. | **Smartphones:** costs $50-$100 in Asia; significant majority can afford to own one. | **Smartphones:** become constant need; daily habits now depend on having smartphone. |
| **Water:** limited source; limited production; designer water; Evian in the 1990s. | **Water:** broad selection of brands; premium price; limited distribution. | **Water:** retailers begin selling house brands to meet demand. | **Water:** bottled water fills daily need; has replaced tap water for many. |

MARKET PENETRATION

ECAN pathways have been instrumental in explaining how the cost of devices such as computers fell by 98% in real terms (accounting for both cost and computational power) over 30 years. We don't actually need computers as powerful as are cheaply available today but we perceive that we do because they are better than the previous generation. Just as we don't need cars that can drive 250 km/h, the capability of cars to do so still drives our perceptions and results in our purchasing them.

ECAN explains how brands (or product categories) are constantly built at the tiers of Exclusivity and Choice and democratized at the category level through distribution (Access) and the transition to Need. The advent of the Internet over the past 25 years has further accelerated this pathway especially through the efficient and rampant sharing of ideas.

This demonstrates that it is absolutely possible for human mobility markets to transition to a fully automated vehicle environment, but only if the market perceptions create the necessity for it.[74]

This Exclusive-Choice-Access-Need (ECAN) process is essentially universal for any successful innovation. Elon Musk implicitly used this in his "Master Plan."[75] First described in 2006 before vehicle automation was considered as a viable consumer market technology, Musk wanted to make automobility energy-sustainable. He described the steps he would take to develop the electric vehicle market:

1. Create a low-volume car, which would necessarily be expensive – **Exclusive**.
2. Use that money to develop a medium-volume car at a lower price – **Choice**.
3. Then use that money to create an affordable, high-volume car – **Access**.

To his credit, he left the **Need** step implied.

If full-vehicle automation is to become pervasive, as is predicted by many, there must be an ECAN pathway to enable this: existing automobile users will not make this change in a single, rapid step. To simplify, we can imagine an ECAN for each level of automation. The one for non-automated vehicles – now over a century old and still creating lock-in – was formed of many ECANs each related to one or another of innumerable automotive innovations. This ECAN has reached the point that the great majority of households in Canada exhibit a revealed preference (Need) to own at least one personal or family vehicle. A minority of these vehicles are still exclusive in their design or cost, and the great majority are highly affordable at the median level of Canadian income.[76]

## 7.3 ECAN for the semi-automated vehicle

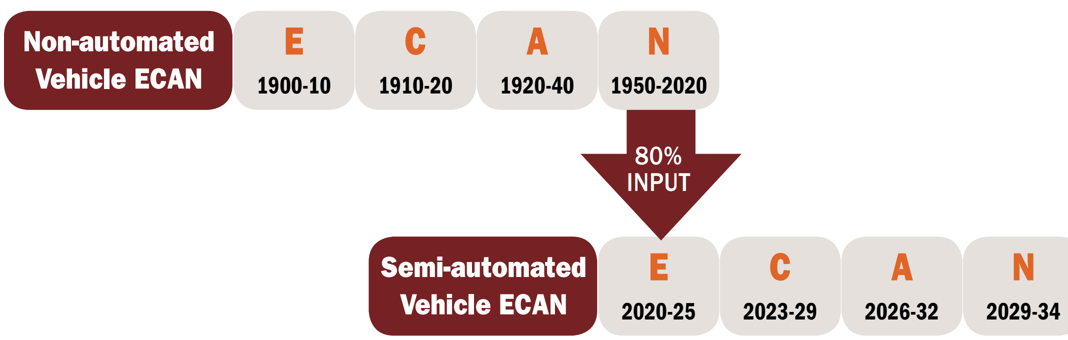
There is already a starter-ECAN for semi-automated personal cars. At the Exclusive stage (and admittedly still early on the semi-automated development curve), we can already buy hands-on, high-end cruise control (essentially SAE Level 2) from companies such as Tesla, Mercedes-Benz, BMW and Infiniti. This technology is still risky, demanding full driver attention and frequent driver corrections – a source of considerable angst among watchers of vehicle automation. We have begun to see a few crashes blamed on driver expectation that the technology is more reliable than is actually the case.

We can expect this ECAN to change along two dimensions: (1) hands-on high-end (Exclusive) cruise control will trickle into more brands (Choice), more models and at lower prices (Access). As the current level of this capability is unreliable however, it is doubtful it will last long or penetrate deeply (Need) into the market and (2) will be soon replaced with a new ECAN for the next level of semi-automated vehicles (SAE Level 3), expected to initiate circa 2018.

Essentially, if semi-automation is to be successful, the current, 100-year-old ECAN for non-automated vehicles will be superseded by another for a real autopilot[77] capability. This will be far more reliable and especially must address the driver attention problem.[78] If this is achieved, then the ECAN for market-sticking, semi-automated vehicles might look like Figure 5 and would dominate the market for household vehicles by the mid 2030s. (This is unrelated to the FSU projection (section 7.1), which is intended to describe fully automated vehicles – SAE Level 5.)

**Figure 5:** **Non-automated Vehicle ECAN vs. Semi-automated Vehicle ECAN**

In this simple discussion example of a potential ECAN for the semi-automated vehicle, note that a majority of existing trip-takers in North America, who currently “Need” personal non-automated vehicles, are positioned to switch to the new ECAN. Populations adopting the ECAN for semi-automated vehicles will be multiplicative or exponential rather than proportional. If 1,000 purchase Exclusive, 100,000 will have it as a Choice in the next generation, and one million would have it as an Accessible expectation by that generation of manufacture before becoming a fundamental Need to be fulfilled at volumes of many tens of millions. The switch over the first 15 to 20 years will be easy and rapid.




This analysis is a simplistic example of a potential ECAN for the semi-automated vehicle. Arguably, this can proceed in linear steps because semi-automation is really an incremental – non-disruptive – business model: the driver stays behind the wheel, perhaps gripping it less often. Automotive companies compete to bring innovations to the market and these innovations would have only modest effects on infrastructure since a driver is required. Semi-automated vehicles would tend to increase congestion, parking and sprawl at a modest rate, but this effect might be offset somewhat by the countervailing effects of fully automated technology, especially if that development were to be sufficiently timely (section 8).

What matters most about the ECAN for the semi-automated vehicle is that there is an enormous, century-old, trillion-dollar industry that wants this to succeed. Only a few of the pre-automation automotive manufacturers are thinking about dividing their efforts between household vehicles and automated shuttles and robo-taxis. So far, there is neither steak nor sizzle in robo-taxi or rob-shuttle markets.

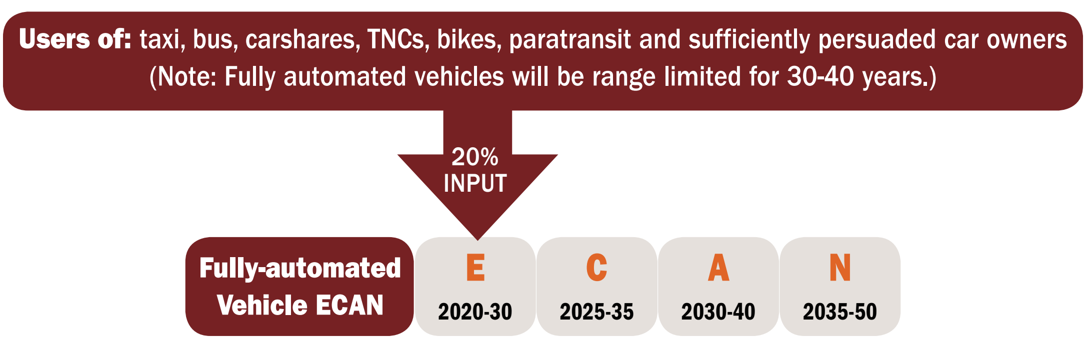
### 7.4 ECAN for the fully automated vehicle

Nearly all the robo-shuttle/taxi ideas have been from newcomers such as: EasyMile, Google, Navya, Local Motors, Baidu and Tesla. Of course, there have been discussions at Ford and GM, but will they make the shift?[79] This is where ECAN is critical. ECAN’s fundamental ability to model buying behaviour emerges from the easy dissemination of information that changes our perceptions about the solutions/offers at hand. Brands inspire imagination and ambition and people consume for those reasons.

Regardless of the overwhelming market force behind the ECAN for semi-automated household vehicles, there will still be an ECAN for fully automated, public service mobility. These two ECANs will compete for market share (buyers vs. riders), money and infrastructure. Right now, the semi-automated ECAN is in the lead by far. Any futurist that projects "we will stop owning and switch to sharing vehicles," needs to explain how the ECAN for the fully automated vehicle will dominate the semi-automated ECAN. This requires more rigour than simply hoping.

**Figure 6: The early adopters of the fully automated vehicle ECAN**

Distinct from the ECAN for the semi-automated vehicle with its 80% input from the existing market (see Figure 5), this illustrative ECAN for the fully automated vehicle draws its initial consumers from an entirely different population of travellers. This is a population less used to Exclusivity and Choice than will be the input population to the semi-automated ECAN, so while fewer in number, they will necessarily be more accepting of the initial range limitations of full automation. As the disadvantaged within Ontario's transportation choice systems, they are used to such limitations.




A new ECAN requires the replacement of the previous ECAN for a given category. And a new ECAN for motorized mobility needs to be three things: better, attainable and scalable in the perceptions of the market – and more so than in the technology of it. This is why many better technologies failed the ECAN test. Betamax is a common example. Its marketers could not communicate why it was better than the existing VHS system even though it was technically superior. The perception held that switching to Betamax wasn't worth the effort or cost. In the 2020s, the household switching costs from non- or semi-automated vehicles to fully automated vehicles will not be worth the trouble because of access anxiety. Any sense of loss of access to trip destinations leads to loss aversion, a powerful motivator in human decision-making.[80] However, the switching costs for public service vehicles such as automated taxi or transit will be worth the trouble as both types of services could thereby reduce costs and increase ridership.

In line with our contention that the fully automated vehicle has no significant household-consumer market, how then would full automation in the form of robo-shuttles and robo-taxis build a significant ECAN in the face of fierce competition from the semi-automated ECAN? That is the subject of the next section.

# 8.0 HOW FULLY AUTOMATED VEHICLES CAN DOMINATE THE NEXT 40 YEARS

**What government action and vehicular infrastructure would encourage mobility digitization and speed up significant deployment of fully automated vehicles?**

As discussed in previous sections, in addition to the lack of a household market for fully automated vehicles, the cultural, market and structural momentum behind vehicle ownership is daunting and strongly favours the semi-automated vehicle. But there are a few cracks opening up that provide an opportunity to put more PKT in fully automated public-service vehicles to moderate the growth in semi-automated household vehicles.[81] Factors favouring the market for fully automated vehicles are:

- **Driver Distraction** is a difficult and possibly unsolvable problem (short of removing the driver from the loop). While there is a common awareness of the danger of distraction with non-automated vehicles, there is a related and more difficult problem with vehicles that are semi-automated and need only occasional operator participation for vehicle control.[82] Carmakers are working on techniques for mitigating an inability to regain driver attention in situations where automation fails or becomes beyond the capability of the vehicle, but semi-automation seems likely to fail to reach the 90% reduction in fatalities and injuries promised by the advocates of automation. Worse, in a complex road network shared by multiple levels of automation, semi-automated vehicles needing to react to unexpected behaviours of non-automated vehicles may make little net difference to crash levels. While there is too little evidence to justify this assertion comprehensively, and we may wish to reserve judgement until the outcome of Volvo's Gothenburg trial (2017), there is sufficient experience to contend realistically that driver distraction is the Achilles' heel of semi-automation. This will spur government action in some jurisdictions.
- The **cost of PKT** in non-owned, driverless vehicles under ideal conditions has been calculated to be less than 25% of current automotive travel costs.[83] Even if a more achievable number is closer to 40%, well-managed robo-shuttle and robo-taxi systems would become more viable to some populations and encourage more abandonment of vehicle ownership (i.e., a greater portion than the current five to 7% that rely solely on transit and taxis).
- The higher **cost of living in denser cities** includes higher costs for retaining a vehicle – especially considering parking costs. This means Marchetti's average 13% travel budget[84] would be strained for a growing number of vehicle owners. This effect, for which there is already some evidence, will spread beyond the millennial demographic and align more with Marchetti's observation than the millennial correlation. The "millennial effect" is really more about travel budgets than age. The correlation with the millennial demographic is real, but a principal cause is the relative lower wealth of the cohort compared to the previous. The effect may be inherited by the next generation and become sustained, but to assume this population has lost interest in motorized automobility may be misleading.
- The ongoing **need for transit** coupled with its persistent failures and rising cost opens an enormous opportunity for SMPs to invest in operation of fully automated robo-shuttles and robo-taxis as our bus systems are threatened by opportunistic entrepreneurial approaches.

- The **technology needs a market** outlet that semi-automated vehicles cannot provide. Newer players such as Uber, Google and Tesla have the ability and motivation to replace current trip-taking by taxi, bus and marginal vehicle users. Once a successful ECAN model for the fully automated vehicle can be established, these firms can dominate the motorized mobility market at the expense of the semi-automated ECAN. It is the business model that matters – being driverless is just an enabler, as was being horseless 120 years ago.
- **Developers** want to minimize parking. Hearing the mantra ”we won’t need parking anymore” and being aware of the uncertain distribution and timetable of markets for fully automated vehicles, developers are in the unenviable position of not knowing how much parking to build, but knowing that whatever they do build will likely be too much within a few years. Because there are many millions of dollars at stake, developers would like to see predictability in this market. Their best course of action is to design to assure the long-range use of shared vehicles that do not need on-site parking, while recognizing that there will be a mid-term transition period of non- and semi-automated vehicles that they must profitably survive.
- **Municipal parking.** The more that cities charge appropriate parking fees – a change that appears to be accelerating thanks to the work of Donald Shoup[85] – the more fully automated vehicles are favoured. Semi-automated vehicles need on-site or nearby parking. Fully automated vehicles do not.
- **Shorter and fewer trips** are being made by younger drivers. While this trend is still not fully understood,[86] it remains evident and means that the automobility value of vehicle ownership is declining for at least some demographic groups. Coupled with density and the cost of living in higher density cities, the Marchetti economics of automobility will increasingly disfavour ownership.
- **Liability issues** will be complex in the case of semi-automated household-owned vehicles due to driver distraction, system errors, component failures and shared responsibility for safe driving. But they will be clear in the case of fully automated vehicles: the liability will be shared among designers, parts providers, manufacturers and operators. Unless the user of a fully automated vehicle hired in public service were somehow criminally negligent, she would have no liability for a crash.

No single issue among these would likely deter a person determined to own a semi-automated vehicle in 2026, or a government wanting to postpone action until after the next election to announce its plans, but taken together would give many vehicle owners and their beholden politicians pause. That pause creates the opportunity for the fully automated vehicle. The combined weight of several of these reasons forces marginal car owners to shift from the semi-automated ECAN to the fully automated ECAN.

If we follow the money and consider vehicle automation from the perspective of trends and business models rather than from the perspective of smart streets, fewer accidents, self-circling cars, repurposed parking lots, the next election mandate or global warming, we will be more successful in building an ECAN for fully automated vehicles to displace both the status quo

ECAN for non-automated vehicles and the impending ECAN for semi-automated vehicles.

By waiting for Silicon Valley to decide the nature of personal automobility, regional governments risk the consequences of being swept up by exponential innovation that government will find hard to track, regulate and manage. If Uber caused regulators headaches in 2015, the disruption wrought by driving automation and robo-taxis in the 2030s will be many times worse, disrupting transit as we now know it.

Since the 1960s, experience has proven to us that we cannot build our way out of congestion by simply constructing larger versions of what we have built until now. And we know our current infrastructure is inadequate for today's task. Yet without an ability to accurately predict the nature of motorized surface transportation vehicles in 2025, 2035 or 2045, we now cannot even contemplate designs for these vehicles, much less build our way out of congestion.

The only way to escape this conundrum is to decide the world we want and then innovate by shaping our use of developing technology to achieve it, rather than waiting until technology shapes it for us. We need to complement our notion of infrastructure to go far beyond physical facilities to encompass the methods, business models, vehicle access and use models, data and labour models that create transportation value. The analogue world of road surface, tracks, heavy transit vehicles, schedules and fixed routes are no longer sufficient regardless of how much of each we deploy. Current transportation and transit models obscure our understanding of what mobility digitization, especially vehicle automation, can offer. It will not be viable to simply replace our current vehicles with driverless vehicles.

As a parallel example, even replacing taxi drivers with Uber drivers was far from a simple exchange. The reason that so few people understand prime time or surge pricing from TNCs, such as Lyft or Uber, is because most people see chauffeurs as employees. But TNC drivers are not employees. They are paid volunteers. Prime-time pricing calls them away from the dinner table or their beds to drive in peak hours or at tavern closing times when rides are needed. The absence of such a mechanism means taxis are unavailable when they are needed and circling pointlessly when they are not needed. Hence, the Lyft/Uber business model provides better service to its users, is cleaner for the city and encourages some users not to purchase a vehicle. It can also be cheaper than the bus in some ride-sharing circumstances. Unfortunately, the TNC business model cherry-picks travellers who can pay. Already, this is profit oriented, demands subsidies, and threatens transportation equity.

Automated vehicles have the potential to make our problems worse, especially congestion, sprawl and a demand for yet more physical infrastructure such as roads and parking facilities if cars are predominantly privately owned. Applied as "Uber" fleets of cheap robo-cabs operated opportunistically by entrepreneurs possibly aided by rogue MaaS apps and with little regard for social equity, they will almost certainly wipe out any residual value in financially stressed public bus systems.

## 8.1 Switching to robotic vehicles from a regional government perspective

How is it possible to initiate such a large social change? In spite of a plethora of unknowns, Ontario and its municipalities can start now to develop a policy direction that is more likely to have a desirable outcome than just waiting.

How should municipal and regional governments begin to respond? Local governments that fight robo-taxi fleets like some fought Uber will lose. The cost per passenger kilometre will be a tiny fraction of the same passenger kilometre on a traditional bus. It would make more sense for government to collaborate in deploying massive shared fleets under SMP agreements. Local governments should plan to disrupt transit head-on in order to create public robo-fleet services in a way that ensures equitable access for every citizen – a concept missing from the current business model of TNCs. In today's world, at a time when fully automated vehicles are just on the horizon, city leaders need to begin creating the pre-conditions for the future they wish to see.

Two critical unknowns among all the uncertainties described above provide an important key to thinking about the infrastructure issues associated with automated vehicles: Will the majority of automated vehicles be owned or shared? Will they gradually be mixed in with, then finally dominate, human-operated vehicles or will they somehow be isolated to carefully constrained applications?

**Owned or shared?** Private ownership will lead to large fleets of registered household vehicles – perhaps 20% greater (relative) than now according to some 2015 reports.[87] Since fully automated vehicles will not require a licensed operator, young, old and disabled passengers can now utilize a dedicated vehicle without a family member acting as chauffer. Hence some families will see owning an additional vehicle as a very rational decision – and powerful marketing forces in the automotive industry will always encourage a high-volume consumption model stoked by year-over-year feature improvements rather than a shared-vehicle model.

Conversely, a shared fleet, if used by a majority of travellers, would mean smaller household registered fleets, dramatically reduced parking infrastructure and less congestion. Ironically, although we might need many fewer vehicles to operate concurrently, there is no indication of fewer vehicles manufactured since shared use means shorter life cycles – i.e., manufacturers will make a similar or greater number of vehicles. Once freed from fixed and constrained routes, and jurisdictional geofencing, a larger fleet with mixed vehicle sizes is far more flexible (and effective) for many public transportation operations. Reduced labour costs per PKT could allow these SMPs to provide an order of magnitude more PKT for only double the labour contingent.

**Freely mixed or constrained and isolated?** There are many operational, social and liability complexities involved in freely mixing non-, semi- and fully automated vehicles on the same roadway, especially when we include pedestrians and cyclists – already a volatile mix even without the semi- and fully automated vehicles. Even as these may be addressed technically, there are other acceptability issues regarding the use of automated vehicles – a large portion of the population, when polled, claim they would not buy them or would be afraid to use one.

Traditional automotive manufacturers will likely prefer the mixed-traffic model, since that implies increased opportunity to sell semi-automated vehicles and justifies many years of gradual additions of safety and intelligence features that nurture an ongoing preference for further vehicle consumption and perpetuation of the household-ownership ECAN. They will mine the rich marketing opportunities across the full spectrum of partial-to-complete robotic enablement taking advantage of the cultural predilection for "my car, my way."

Using ongoing improvements in automation to add new and compelling features to each model year continues the common commercial practice of "Feature-Creep." Certainly, many automated and safety-related features are not to be disparaged, but the year-over-year business model of incrementalism to stoke envy and promote car sales remains the same.

> **"… a consensus is emerging that the journey to [full automation] will be a progressive one in which small steps are made along the way and new features are added to vehicles every six to nine months or so."**
>
> — Clearwater International, Clear Thought (newsletter), March 2015

As discussed earlier, new players such as Google, Uber and now Ford[88] see automation feature-creep as unworkable and promise full automation sooner than do traditional players. Astro Teller, head of the business division overseeing the Google automated vehicle, explained this graphically at an SXSW Interactive keynote, March 2015:

> … everyone who signed up for our (self-driving car) test swore … they [would] pay 100 percent [sic] attention to the road, and knew that they'd be on camera the entire time … people do really stupid things when they're behind the wheel. They already do stupid things like texting when they're supposed to be 100 percent in control … so imagine what happens when they think 'the car's got it covered.' It isn't pretty. Expecting a person to be a reliable backup … was a fallacy. Once people trust the system, they trust it. Our success was itself a failure. We came quickly to the conclusion that … the car had to always be able to handle the situation. And the best way … was to design a car with no steering wheel – a car that could drive itself all of the time.[89]

To date, reportedly, all but one accident involving Google's automated vehicles have been blamed on drivers of non-automated vehicles. And the several accidents involving Tesla's autopilot (including two fatalities as of press time for this report) have been blamed by Tesla on the drivers involved, presumably implying distraction made easy by over trusting low levels of automation. This brief history suggests that Feature-Creep may fail as semi-automated vehicles improve but still require driver supervision leading to greater accident risk when mixing automated and non-automated vehicles.[90] If this happens, full automation (Google's stated position) will become preferred. But a region or nation cannot quickly take up pervasive full automation as Feature-Creep competition reveals itself as a failing model for transition from semi- to full automation.

## 8.2 Transit Leap

Many planners, transportation engineers, environmentalists, safety engineers, and transportation decision-makers want the benefits of fully automated vehicles. Trip-takers want the benefits of getting anywhere, anytime, starting immediately and arriving conveniently. How can we get to that easily-conjured-but-far-reaching transportation system using shared robotic vehicles while providing the instant trip-gratification that vehicle owners now enjoy, given the several barriers described earlier?

If mixed traffic is going to be problematic, it would make sense for regional governments with SMP involvement to begin immediate deployment of available, fully automated shuttle vehicles in constrained, low-speed, traffic-calmed, first-and-last kilometre applications, addressing immediate solutions rather than waiting or experimenting with longer range, longer distance, higher speed, higher-risk, highway technologies.

We propose the concept of "Transit Leap," which structurally parallels SAE's well-known five levels of vehicle automation (see Figure 7). Transit Leap comprises a series of gradual spatial expansions that deploy fully automated vehicles from the outset. Each expansion grows in capability with technical maturity and spreads in range like ink-blots fuelled by user demand. The five SAE levels grow via pervasive consumer acquisition; the five Transit Leap levels grow by spatial expansion and aggregation. The SAE levels are agnostic regarding ownership. Transit Leap stages are specifically intended for public service and its robo-shuttles vehicles and robo-taxis would be operated by SMPs, local government or corporations.

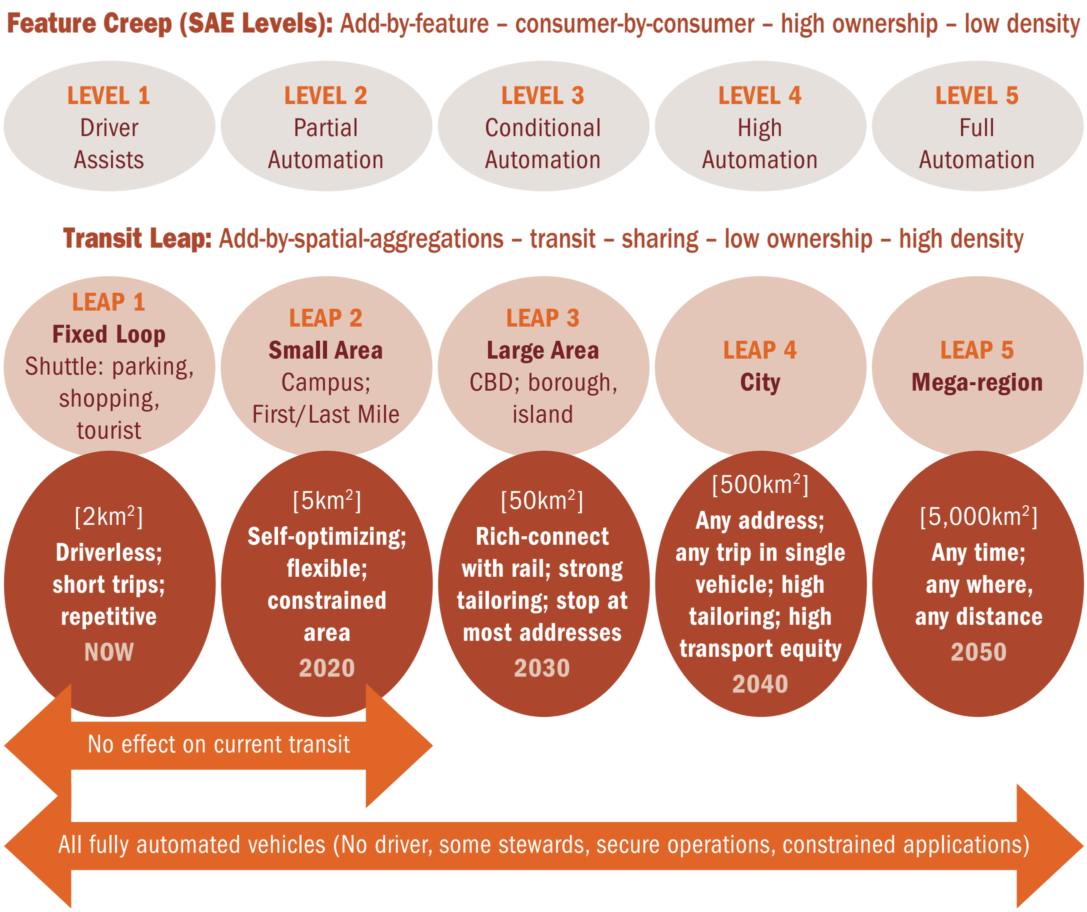
Leap 1 begins with the simplest of applications: short, repetitive, fixed routes. The automated minibuses trialed successfully by CityMobil2 in several European cities exemplify the Leap 1. These early-generation, ten-person robotic shuttles follow fixed, repetitive routes of a couple of kilometres for required activity hours each day. Leap 1 is cautious, highly constrained, and low speed. It incorporates close oversight, tele-monitoring, and includes on-board stewards.

> **"Transit Leap means public-use, robotic, shared-mobility applications that start small, expand by demand, grow, merge, spread and substantially transform mobility for all urban areas on the planet."**
>
> — endofdriving.org at the 2016 Canadian Transportation Research Forum

Numerous first-and-last-mile and other small-scale applications such as parking lot shuttles at airports, stadiums, universities, industrial parks or transportation hubs would be serviced by Leap 1 and 2 robo-shuttles running at modest speeds on clearly marked lanes and tightly constrained to regular service on regular routes. Human attendants to provide comfort to early users would be eased out gradually. Such applications are numerous and can be expanded with technical success and public acceptance to longer routes and allowing for passenger pickup requests by smartphone, beginning to act more like a jitney than a shuttle. Retirement communities could use such vehicles for on-demand trips for access to local shopping, entertainment, medical services and worship.

**Figure 7: Transit Leap — Alternate Path to Full Automation**

An alternative to automotive Feature-Creep, Transit Leap's five spatial levels of transit operation mimic SAE's five technical levels of vehicle automation. The difference is that the constrained operation of each Transit Leap means that all five levels of Transit Leap use driverless vehicles. This trades speed and range in Leaps 1 and 2 in order to leverage the benefits of automation far earlier for denser, more frequent and more flexible public service offering.




Over the next two decades: cities could begin with smaller urban bus routes at low speeds on constrained lanes at grade and without barriers, set up like bicycle lanes (see photo examples on p. 47 and 48). These city systems would have the experience of the parking shuttles, universities, retirement communities and industrial parks to rely on. City routes could integrate, expand in number, distance and flexibility until public transit (excluding trunk lines and existing rail) and eventually, even household ownership is dominated by automated mini-buses and robo-cabs. As Leaps 1 and 2 merge into Leaps 3 and 4, robo-taxi and robo-transit are blended into a continuous service spectrum that includes traditional rail and active transportation. Leaps 2, 3, 4 and 5 would be served by MaaS systems such as described by MaaS Global's Sampo Hietanen.[91]

### 8.2.1 Case Study: CityMobil2 (Completed, Leap 1)

To date, the most extensive pilot for automated road transport systems has been CityMobil2. This was a multi-stakeholder project co-funded by the EU's Seventh Framework Programme for research and technological development (FP7). It deployed in seven urban environments in stages across Europe from 2012-2016. These were operational trials lasting an average of four months each (see Table 2). Two manufacturers supplied a dozen self-driving mini-buses (see photos below and on p. 48). Each had no driver, was remotely monitored, and was accompanied by a steward. In total, some 60,000 passengers experienced these vehicles over a total of 18,000 trips and 25,000 km. Because there was no human to grab a steering wheel – or even a wheel to grab – "this was something unprecedented."[92]

**Table 2: The participating cities on the CityMobil2 Automated Road Transport System pilot platform**

| CITY | BEGIN | END | LENGTH | TRIPS | DISTANCE | PASSENGERS |
|---|---|---|---|---|---|---|
| Oristano | July 2014 | Sept. 2014 | 1.3 km | 714 | 1,836 km | 2,327 |
| La Rochelle | Dec. 2014 | Apr. 2015 | 1.8 km | 2,100 | 3,778 km | 14,660 |
| Lausanne | Apr. 2015 | Aug. 2015 | 1.5 km | 4,647 | 6,970 km | 7,000 |
| Vantaa | July 2015 | Aug. 2015 | 1.0 km | 3,962 | 3,962 km | 19000 |
| Trikala | Sept. 2015 | Feb. 2016 | 2.3 km | 1,490 | 3,580 km | 12,138 |
| Sophia-Antipolis | Jan. 2016 | Mar. 2016 | 1 km | 3,263 | 3,100 km | 3,700 |
| Donostia San Sebastian | Apr. 2016 | Aug. 2016 | 1.2km | 1,968 | 2,362 km | 1,918 |

Automated (driverless) mini-buses (six seated, six standing) move along fixed routes with fixed stops at a maximum speed of 40 km/h. Vehicles were remotely monitored and accompanied by a steward to answer questions, explain the program and provide comfort.

The key difference between CityMobil2's full automation focus and the North American focus on semi-automated vehicles exemplified by Tesla's autopilot is a focus on transit vs. personal vehicle ownership. Automated transport systems are deemed by CityMobil2 to play "a useful role in areas of low or dispersed demand complementing the main public transport network. All [participating cities] recognize the potential of vehicle automation as part of their public transport network."[93]

Lane markings were made for the other vehicles as well as pedestrians and cyclists to show the rights-of-way for the automated vehicles.

In addition, research was … "undertaken into the technical, financial, cultural, and behavioural aspects and effects on land use policies …"[94] "What we are really looking for is how automated vehicles will be integrated into the transport system of a city."[95]

Critical as well was the attention paid to certification:

> CityMobil2 developed a certification procedure which is based on considering together the vehicle, the infrastructure and the communication system to ensure safety. So we don't rely exclusively on the sensors and the technology onboard the vehicle. We divide the infrastructure into stretches and analyze all the possible threats that can arise and how the vehicle will react to those threats. This is key to certifying that vehicles and systems will be absolutely accident free.[96]

And CityMobil2 managers are aware there is more to do:

> There are still many challenges to be tackled to support automation … so we still need to fund activities. The main challenge will be field operational tests to deploy these systems.[97]

At the culmination of the four-year CityMobil2 project, four EU member states now have regulations permitting driverless trials: Finland, Greece, Sweden and The Netherlands. Two others, Norway and Switzerland, will be announcing permanent implementations and four cities are deploying permanent installations.[98]

### 8.2.2 Case Study: WEPod in The Netherlands (Leap 1 and 2)

The province of Gelderland in the Netherlands has undertaken an automated shuttle project, WEPod, slightly more ambitious than any single one of the CityMobil2 projects routes: eight kilometres between a local train station and campus and two kilometres around campus (see Figure 8). Its first phase, with 300 passengers, runs from September to December 2016. Its initial operators are developing a knowledge base before turning the system over to a new operator for the next phase. They expect to run three or four trips per day with non-paying passengers by the end of 2016.

There are two shuttles upgraded[99] from those used for CityMobil2 (it uses vehicles and systems from one of the CityMobil2 suppliers, EasyMile), these vehicles carry six to 12 passengers, move at 25 km/h, are monitored remotely, and employ a human steward (which is still required by regulation) with access to an emergency stop button.

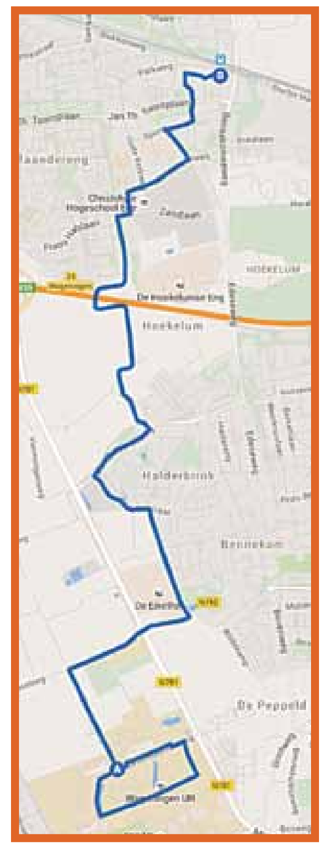
The eight-kilometre route between the campus and the train station shares the roadway with existing traffic, including cycling infrastructure. Passengers can book the WEPod with an app that allows selection among the stops. In this early phase, the WEPod operates as a fixed-route shuttle.

In a control room, there are three screens permitting a remote operator to see what the vehicles' cameras see. The control room is shared with other functions, so the controller is dividing his attention among other tasks.[100]

While CityMobil2 routes were also shared with existing traffic, the WEPod route to the train station is about five times longer than the average CityMobil2 route; hence, it interfaces with more non-automated traffic, making the operationalization of this project a critical next step. (The plan for that was not disclosed.) Integration with existing traffic is as important as integration with existing transit systems (in this case, an interurban train).

As discussed earlier, integration with existing systems is harder and more critical than the automated technologies themselves. Automation provides enablement. Integration provides solutions.

**Figure 8: The WEPod Route:** eight kilometres between train station (top) and University (bottom); two kilometres on the campus.



* * *

The lessons that Ontario should most learn from WEPod are about deployment and adoption rather than about the automation technology itself, which in the form used in this project is becoming increasingly common.

The WEPod project could be emulated in first-/last- -mile systems around our GO stations to relieve morning competition for parking at the stations.

### 8.2.3 Case Study: Babcock Ranch (Future, Leap 1-3)

One of the earliest simulations to examine the efficacy of substituting fleets of robo-taxis for privately owned vehicles included Babcock Ranch, a greenfield community in Florida planned for 50,000 people and 20,000 homes over 70 km$^2$. In its current, planned state, this will be a "Leap 3"-sized project in the early 2020s.

In the original 2012 simulation,[101] Lawrence Burns, et al., treated Babcock Ranch as an island: all internal trips were modelled in driverless robo-taxis. For trips beginning or ending outside the Babcock Ranch community a privately owned car would be assumed, and these were excluded from the simulation calculations.

Using independent demand estimates, the study assumed a total of 115,000 internal trips per day at full build out, or an average of 2.3 trips per day per person. The average trip length was estimated to be 5.6 kilometres (3.5 miles) with an average vehicle speed of 40 km/h.

Given the settlement geography, to achieve average wait times for vehicles of under a minute while minimizing deadheading, 3,500 ± 500 vehicles would be needed at peak. Assuming vehicle costs equivalent to conventional mid-sized sedans, total fleet costs calculated out at $0.30 per kilometre and $1.60 per trip. At 2.3 trips per person/day this is just under $4/person/day. Costs remained constant once the number of customers reached 5,000; they were about 25% higher if the customer base dropped to 1,000.

What is valuable to consider is that this program is initially intended to reduce vehicle ownership to an average of one per family and not a program to end ownership. At 20,000 homes, then, this simulation is assuming 20,000 personal vehicles and 3,500 shared robo-cabs for 50,000 people, a per capita vehicle population of 0.47. This is just over half of the current U.S. per capita vehicle population.[102]

As of August 2016, Kitson and Partners, the developers of Babcock Ranch, and advised by Burns, have issued a RFI for suppliers of robo-taxi systems including vehicles, EV charging infrastructure, mobility network managers, fleet managers and communications networks.[103] (see Table 3; taken from Table 1 of the Babcock Ranch RFI).

**Table 3: Babcock Ranch residential and projected automated vehicle growth rates**

This is the target supply for the first five years of Babcock Ranch – 400 vehicles for 2,839 homes, each retaining an average of one household vehicle, meaning a per capita vehicle population of 0.46 (2839+400) / (2839*2.5) matching the projections from the 2012 simulation.

| YEAR | AV PHASE | NUMBER OF NEIGHBORHOODS | TOTAL ABSORPTION (UNITS) | NEW VEHICLES | TOTAL FLEET SIZE (2 ROUND-TRIPS/DAY) |
|---|---|---|---|---|---|
| 2017 | Phase 1 | 2 | 88 | 40 | 40 |
| 2018 | Phase 1 | 4 | 519 | 60 | 100 |
| 2019 | Phase 2 | 5 | 1114 | 100 | 200 |
| 2020 | Phase 2 | 5 | 1867 | 100 | 300 |
| 2021 | Phase 3 | 6 | 2839 | 100 | 400 |

Vehicle estimates based on two-passenger vehicles, two round trips/day/resident with less than five-minute vehicle wait times (from Babcock Ranch RFI, July 2016, p. 4).

Since Kitson and Partners is planning to expand from 40 to 400 vehicles to service from 88 to 2,839 families in the first five years, this starts out small (Leap 1) and grows exactly as prescribed by Transit Leap to reach Leap 2 in under five years. Beyond the phases shown in Table 3, Kitson and Partners ultimately intend a build out to 19,500 housing units. If the same per capita ratios are maintained, a robo-fleet of some 2,750 vehicles (at the lower end of the original simulation calculation) would be required and with the expanded area, scheduling, maintenance, and management, a busy Leap 3 would be deployed.

Already, the intention to expand this to other communities is explicit in the RFI:

> The technical, safety and customer acceptance data obtained from Babcock Ranch will enable rapid expansion into similar communities. These include new and established communities. There are over 5,000 gated communities in Florida alone that represent rapid growth opportunities.

Each such community would pass through Leaps 1 and 2 and larger ones to Leap 3.

There is a further opportunity that was unexplored in either the simulation or the RFI. Once Babcock Ranch is well on its way to a Leap 3 deployment in the early 2020s, the evident and rapid improvement in SAE Level 4 automation will enable well-mapped, fully automated trips into the surrounding 50-kilometre radius from Babcock Ranch to nearby Fort Meyers, Cape Coral, Lehigh Acres and Southwest Florida International Airport. This area supports a permanent population of more than 500,000 as well as a significant tourist industry. Its low density and easily navigable roads provides a significant opportunity for an early Leap 4 breakout centred on the Leap 3 deployment of Babcock Ranch.

This, coupled with potentially hundreds of smaller Leap 1 and Leap 2 communities each linking automated trips to neighbouring communities, makes Southwest Florida an ideal breeding ground for robo-taxi fleets.

### 8.3 Transformation of ownership – not just disruption of driving

The goal of Transit Leap is not to incrementally improve surface transportation as we might with narrower lanes or non-signalized intersections, but to utterly transform it. Transit is cripplingly expensive per ride and used across all trip types for only 7% of passenger kilometres in Canada (5% in the U.S.). Shared service vehicles such as taxi, TNC and carshares although growing in number now, still produce statistically invisible passenger kilometres on a North American basis. Private vehicles – blanketing our cities and streets while idle 95 percent of the time – handle about 93% of passenger kilometres in Canada, even higher in the U.S.

Local governments in Ontario should begin immediately the process of choosing where to deploy a modest number of automated minibuses in Leaps 1 and 2 applications. Already, the GTHA would not be the first. By the early 2020s, authorities could begin to merge multiple Leap 2 applications, and be ready to merge further with growing fleets of geo-fenced robo-cabs. By the latter half of the 2020s, fledgling Leap 3 networks would start to erode significantly the need for private vehicle ownership.

Provincial and local transportation agencies should set a long-run target of 80% of all passenger kilometres to be travelled in shared fleets that may comprise public, corporate, SMP or co-op vehicles and are busy from 40 to 80 hours weekly instead of only 8.4 hours as is the case for the average Canadian household vehicle today. This target would motivate a regional community of business and government leaders to innovate how such a fleet could be financed, built, maintained, managed and priced. Planners could begin to work out how to park this fleet in off-peak hours, how to power it, how to re-purpose liberated downtown parking areas. Real estate interests could begin the planning process for turning parking structures to other uses. Community interests might determine whether to re-purpose parking lots as green spaces or places for new housing. Public works departments and planners could turn street parking to bicycle paths.

If regional leaders do not set such an assertive target, the ongoing experience of automotive manufacturers luring consumers with a high, personal vehicle consumption model will dominate the urban mobility scene with unfortunate consequences – more traffic congestion, more land consumption for parking, and more vehicles on the street than are required for the personal mobility that people want and need. It will also leave our bus transit systems exposed to competition (and destruction) by the new mobility entrepreneurs.

As communities start thinking who would be best to deploy such fleets, it is time for forums to discuss the incentive and regulatory structures that would fit our Canadian values. Ideas should be collected regarding ownership models that would provide the flexibility, sustainability and equity we need. Automated vehicle technology increases the attractiveness and utility of fractional ownership, co-op fleets, courtesy-shopping fleets, and P2P fleets. In his 2016 book, Don Tapscott explains that blockchain technology has the potential to utterly change the trust model for sharing vehicles, further increasing the value and reducing the costs of sharing – even destroying Uber's current intermediation model.[104]

The alternatives of fleets owned and managed by large corporations should be included in planning and regulatory scenarios. Corporations, universities and professional groups should be provoked to think about a role in sponsoring affinity fleets managed by co-op transportation operators. What kinds of government guides for pricing, service and response times will be needed to maintain or increase social equity? How could the forces in the competitive market be turned to this goal? All this, and more, is worth discussing now in government-business forums.

# 9.0 VIABILITY OF TRANSIT LEAP

**The stages of Transit Leap, while plausible are simplistically drawn. Is the concept really suitable? One can imagine Transit Leap 5 as the final stage in the automotive utopia promised by automation if we were able to bypass the intermediate Transit Leap stages and especially if we are able to bypass – or at least minimize – the quadrillion kilometres of mixed semi- and fully automated traffic. How might Transit Leap numbers settle out? How might Transit Leap fit with societal trends already in the works?**

## 9.1 Numeric Viability

To give the reader a back-of-the-envelope sense of the number of vehicles that might be involved in the GTHA in 2050 with and without Transit Leap, we offer the following comparison.

The population of the GTHA is estimated to grow to about 10.5 million by 2050. Given a business-as-usual per capita vehicle ownership model (650 per 1,000; no change from now), and a simple linear increase, we would expect a total population of 6.8 million up from our current vehicle population of 4.3 million. If Transit Leap hit its target of 80% of PKT in non-owned (shared) vehicles, we would expect the GTHA in 2050 to require between 150,000 and 250,000 automated public service vehicles of sizes predominantly ranging from two- to 12-seat vehicles. In addition, we would target 20% of the light-duty vehicle population to remain privately owned – 1.36 million vehicles – for commercial, service and special needs. The total number of estimated registered vehicles, then, would be approximately 1.6 million compared to the 6.8 million or 24% of the BAU projected linearly from now to 2050.

To make this calculation, we first determined the number of vehicles in motion at peak hour to range between 5.5% and 7% of the vehicle population in 2014.[105] We then extrapolated that number to an expected 2050 demand and targeted 80% of the PMT represented in that demand to be in a non-owned vehicle. The range was derived by manipulating occupancy to be between 1.5 and 2.5. (Remember, there would be an optimized mix of two-passenger to 12-passenger vehicles, among other optimizations, making this target easily reachable, provided the GTHA reached 80% compliance with respect to non-ownership by 2050.

## 9.2 Trend Viability

In his recent report focused on infrastructure in Ontario,[106] author Michael Fenn explains the impacts of Technology; Urbanization and Globalization; Social and Demographic changes; Economic and Workforce changes; Environment and Energy trends; and Political and Fiscal trends. Fenn further outlines 11 impacts of these megatrends to describe the world we are moving toward. These impacts shrink distances, times, scales and margins, converge functions, favour customization, reverberate global impacts as local impacts, respond to climate change, alter society's priorities, demand consumer-driven urban design, and ensure that short-term thinking will threaten progress and sustainability. Any infrastructural ideas or proposals – such as Transit Leap – that reach into this future will either contribute to these 11 impacts or be stopped by them.

In this section we look at how Transit Leap stands up to the 11 expected impacts of the "Big Six" megatrends "that will affect infrastructure and infrastructure decisions through to 2030 and beyond." Specifically, will Transit Leap contribute to or compete against these evident trends and impacts?

**Impact 1: Distances will shrink.** In its mature stages (Leaps 4 and 5), Transit Leap "shrinks distances" by lowering the cost of distance in terms of reduced pain and inconvenience as well in terms of PKT cost. That's good for Transit Leap, of course, but may imply consumption of more trips. As with any technology that improves the convenience of consumption, consumption increases. In this case, the consumption of publicly available transit/taxi-type services would increase.

**Impact 2: Elapsed times will shrink.** The time cost of a trip is repurposed to activities more valuable than steering, accelerating and watching for traffic lights turn green – an activity on which the average Canadian driver now spends 6.25% of her waking life. Hence elapsed time, in the sense of wasted time, will shrink. Such shrinkage would represent a recovery of about 21,900 waking hours over a driving adult's lifetime.[107]

**Impact 3: Scale will shrink.** Transit Leap shrinks scale in numerous ways:

- vehicles would shrink: SOVs would be two-passenger vehicles, off-peak buses would be 12-passenger shuttles, on-peak buses would be split into four shuttles with passengers assigned optimally to minimize stopping (thereby reducing traffic impedance).
- buildings that are passenger origins or destinations can shrink as they will need little or no parking facilities for the automated vehicles carrying arriving or leaving passengers.
- energy consumption will shrink because the ratio of vehicle-to-cargo weight is reduced dramatically (vehicles do not need to be oversized to carry one or two people and vehicles can be light-weighted since they are safer).
- roadway can shrink with the removal of street parking and this can mean wider sidewalks or bicycle paths.
- distance between human-use buildings can shrink because fewer parking lots would need to take up long parts of city blocks.

**Impact 4: Functions will converge.** Given digital management, logistics can manage moving people and goods in the same vehicle:

- As an example, just as we now have ride sharing apps (such as Uberpool, Uberhop and Lyft Line), we can have load-sharing: for a fare discount some passengers would agree to go slightly out of their way to pick up and drop off a package[108] (this might involve digital mini-hubs to hop packages over longer distances).
- Vehicles used during peak hours to move people can be used off hours to move goods.

**Impact 5: Margins will shrink.** Competition among automated fleets will give rise to auction-type behaviour. Just as you can buy overstock books on Amazon for pennies (plus shipping), off-hours fleets will offer rides for pennies plus operating costs. This will tend to flatten congestion peaks and reduce congestion (effectively reverse tolling). This kind of transparent mobility digitization will squeeze all the margins out of mobility provision, except when congested (surge pricing). This will also help to provide transportation equity while influencing peak choice behaviour.

**Impact 6: Expect individual customization.** By Leap 3, Transit Leap vehicles would be provided in a number of styles and sizes; this variability would increase through Leaps 4 and 5. The purpose of this is to match the ride required as closely as possible with a right-sized vehicle. A fleet of significant size can manage vehicles of varying styles models and prices. The vehicle that responds to a MaaS call would be customized to the degree available provided the users stated wait tolerance.[109]

**Impact 7: Global impacts will become local impacts.** If the developed world moves toward reduced vehicle ownership this will affect Ontario's manufacturing – how vehicles are designed, made, sold, deployed and managed would change. If Ontario were a leader in this, we would contribute to a global change that would boomerang to our local benefit. If the developing world moves more quickly – as some parts inevitably will – this will narrow the global productivity gap reducing the relative economic clout of the developed world, tending to constrain Ontario's relative growth and prosperity.

**Impact 8: Climate change will be accepted, but will its consequences?** While Transit Leap for the GTHA is a model to move people and goods in a region that is suffering from a massive infrastructure deficit while facing down the uncertainty of vehicle automation, it is also a model that recognizes climate change. Because Transit Leap minimizes fixed and rigid infrastructure, it is more resilient to the expected consequences of climate change.

**Impact 9: Demographics will change society's priorities.** By 2050, the target for the complete (80%) transition to Transit Leap, the cohort of drivers that obtained their driver's licence at 16 years of age and their first car shortly thereafter, will no longer be driving. And the cohort we now call millennials will be in their 60s. Not only will these demographic shifts change social priorities with respect to a vehicle ownership, Transit Leap will change social priorities for generations to follow. Social priority change can be influenced by the deployment of technology. Transit Leap is one example.

**Impact 10: New consumer-driven urban designs.** Every Transit Leap trip is exactly tailored. No robo-shuttle makes an empty trip just because it was scheduled to do so. No robo-taxi cruises to seek a fare. This means that travel patterns are only constructed from vehicles that are making a trip with a goal to move a person or a parcel. Hence every trip is optimized to urban design and urban designs can be tailored to trip patterns. Consumer behaviour drives designs and designs drive human behaviour. Of course that was always true but badly distorted by the burden of massive household fleets, parking, the rigidity of fixed transit routes, one-size-fits-all transit vehicles and taxi fleets artificially constrained by medallion systems. Just as consumer-driven taxi choices, re-enabled by Uber, focused a sharply critical light on the inadequate business model of the then-current taxi industry, the automated vehicle will do the same for the inadequate business model of current urban bus transit. The current urban design and practice of bus transit – now seen as critical and preferred – will be seen increasingly as flawed by consumers and in need of transformation. Revealed transit preferences will shift when the first robo-taxis appear.[110]

**Impact 11: Short-term thinking will threaten progress and sustainability.** Transit Leap requires long-term thinking ahead to a time when mobility digitization makes mobility a widespread and preferred public service and the conveyances most people use are part of urban infrastructure rather than personal artifacts. Without a result comparable to the one Transit Leap is targeting, congestion will not improve, the infrastructure we have now including that which we are building will never be enough, and our systems will not be sustainable.

## 9.3 Service delivery and social equity

> A system that is slow to respond to growing technological trends could result in a worst-case scenario of growing transportation fragmentation and dwindling capacity unable to meet the needs of the GTHA's inhabitants.
>
> By the end of 2020, the GTHA's crowded public transit system has only become more overburdened as many necessary expansions to the network are still not completed. In this context, private transportation alternatives such as ride-sourcing have grown significantly in popularity. While the specific impact of this growth is unclear, congestion has clearly increased. Worryingly, these private alternatives are increasingly skimming riders from the public transit system's most lucrative routes. This flight to private alternatives has begun to sap the political will to subsidize transit services that many medium- and high-income citizens are using less and less.
>
> — Sharing the Road, Mowat Centre, 2016, p. 37[111]

Bluntly, Ontario has three choices:

1. Continue as we are and be completely outrun by purely commercial mobility digitization and the mobility Internet to the potential detriment of the megaregion, its transportation systems, its inhabitants and any remaining land-use coherence.
2. Embark on a massive refitting of our public transit systems for automation, which would be risky, confusing, unaffordable and endlessly debated.
3. Start now to determine how to involve and regulate private capital, technology, and operation of people and goods mobility for 2020-2050.

One of the biggest risks we face is that we will polarize into separate camps for options 2 and 3 thereby continuing the flawed, politicized, planning process of the past three decades – in other words, we will make choice 1 by default.

Throughout the rollout of Transit Leap, the preservation of social equity must remain a key value. But it is not the challenge that some public-ownership advocates contend (witness the current debate over ownership of Hydro One). Government ownership of physical, digitized transit is not necessary, and in some cases may be less efficient than private investment and operation. As with natural gas and other "private" utilities, the key to involvement of government is effective, industry-focused, public-interest regulation. Regulations are problematic when they are used as a restraint-of-trade or job-preservation measure, as it has been for generations in areas like taxi and motor-coach regulation, as well as in municipal regulation of some trades (barbers, plumbers and electricians, for example). Regulation is also occasionally simply a surrogate for taxation. One might argue that both of these elements are part of the Uber and Airbnb discussions.[112]

Many municipalities have experience with ensuring social equity and universal access in a variety of fields, without taking on the responsibility of direct delivery. For example, municipalities award contracts to the YMCA to build facilities and run recreation programs for a geographic area, conditional on meeting certain program delivery obligations and goals. This approach allows municipalities to reduce their operating costs for recreation staff and to attract philanthropic contributions to capital costs, which the municipality could not typically attract. The same applies to regulation of those private and non-profit entities operating transitional homes. If structured properly, we might also address the difficult issue of mobility for disabled travellers by using human stewards on SMP robo-shuttles – including another potential for philanthropic involvement.

Transit Leap is fully amenable to government regulation of private investment and operation. Government could set SMP fleet performance goals in terms of PKT per vehicle TKM (tonne-kilometre) similar to what the USDOT does now with CAFE standards. PKT per TKM over time could be set to rise over, say, 25-year mandates. To achieve this, vehicles would be light-weighted, ride-sharing increased, routes and schedules continuously and autonomously optimized by real-time demand, people and goods movement integrated and weight credits traded among competitors. Performance measures can be set to penalize cherry-picking of lucrative service areas and demographics, wasteful and confusing service duplication by competing providers, and underservicing of hard-to-serve routes.

SMP contracts will need to be designed to cross-subsidize low-volume routes with the high-volume routes and to maximize the synergies of an integrated network, especially in suburban settings. The jurisdictional transit boundaries that limit the viability (and desirability) of bus transit in our many cities and towns mean the use of a personal vehicle today is far more preferred than is public transit. Transit Leap can move us from the local area networks of current bus systems to regional area networks for mobility – organic expansion of the Mobility Internet.

Before we can reach that state, we need to address the first- and last-mile issue for which the first stages of Transit Leap are intended. Imagine the last-mile approach taken by cities like Santiago, Chile, or Johannesburg, South Africa, where the rapid transit lines are built and operated by government or its transport entities, and operated at a low per-ride cost and with relatively low fares. But the "feeder" system is largely small-scale private operators of jitneys and vanpools or local buses. The quality may not always be to developed world standards, but the format anticipates Transit Leaps 2 and 3. Uber and Lyft are already demonstrating such feeder systems in North America.

The most costly part of a pre-digital transit system is the low-volume / high-peaks, diffuse local bus transit networks which provide service in low-density neighbourhoods especially because of large, expensive vehicles and well-paid public sector drivers and supervisors. If that feeder system is left to the private sector, the marketplace offers a more flexible, responsive, and cost-effective alternative to publicly operated transit. Historically, the trick has been to maintain social equity (reasonable fares, safety, and convenience for hard-to-serve areas and populations), as well as to ensure peak capacity. But with appropriate deployment of automated vehicles, more efficient solutions to those problems are now on the horizon. New transportation models, coupled with regulated fees and minimal subsidies, offer a realistic opportunity to allow the public sector to focus on what it does best: trunk transit lines, with high-end technology and infrastructure that creates its own secondary transit and real estate markets. Subsidies are targeted and adjusted to daily commuter use where required. This approach leaves the costly feeder system to a regulated private market, using new technology and new delivery models, which are likely to be updated far faster than government can respond.

### 9.3.1 SMPs and service delivery[113]

World experience with private-public partnerships is mixed, so we must exercise significant care. In the U.K., the government experienced cherry-picking of lucrative routes. This resulted in wasteful, confusing duplicate bus services by competing commercial providers, along with no service or poor service on the hard-to-serve routes, without the former capacity to cross-subsidize from the high-volume routes. Incautious structuring of SMP contracts risks shattering the synergies of an integrated network, especially in suburban settings.

On the matter of achieving public objectives, SMPs should always be framed as a tool, rather than a philosophy. We do not do a very good job of targeting subsidies, either by subsidizing systems or subsidizing classes of users. We should rely more on the tax system rather than subsidies to manage social equity. We should also favour all-in, full-cost for some, if not most infrastructure use, to send signals that discourage waste, use at peak hours (or midnight troughs) and building infrastructure to excess capacity. Graduated fares – distance, time of day and, in the case of GO, adding fees for car parking – can also help.

# 10.0 OWNERSHIP IS MORE IMPORTANT THAN THE TECHNOLOGY

**We hold no grudge against the automobile. It is not the culprit. The car serves us much better than the horse that came before it. But the chorus of complaints directed at the automobile bears a striking parallel to the complaints our grandparents and great grandparents levied against the horses that dominated our cities at the end of the 19th century: the manure, feces-filled dust, typhoid-carrying flies, noise, stench of carcasses and urine, injuries and congestion.**

Today, 120 years later, having access to a personal or household vehicle has multiple benefits: immediacy, availability, status, privacy, hygiene and convenience. The simple value of routine habits to reduce the cognitive load of trip planning and preparation including the fact that you may need a baby seat in the back or hockey gear in the trunk makes ownership more desirable. The car is a compact extension of your living room, your office and your kitchen table. "Need" in the ECAN for the personally owned automobile is more tightly locked in than many wish to admit for all but marginal car owners.

So what difference could Transit Leap make if it were to help change the fundamental cultural attachment we have to car ownership?

## 10.1 What harm does owning cause?

As individuals, but even worse as a species, we have developed inefficient practices regarding automobiles. Our practices are the problem, not cars per se. After all, cars can be light-weighted, right-sized, electrified and automated.

Many of the complaints we have about cars are either caused or made worse by the fact that we as owners and drivers choose and operate these vehicles remarkably inefficiently. This inefficiency has resulted in a substantial shared loss of travel effectiveness both in time and cost. Through our own individual and group behaviors we shrink the Marchetti Wall[114] and reduce considerably the value of what an hour's worth of daily travel can provide for our 13% budget. Ironically, it is we users of the automobile that manage to diminish the efficacy of automobility that we so passionately defend against train, bike and bus. If there is a war on cars, then the greatest enemy of automobility is the collective driver sitting behind the wheel.

**We drive very badly.** We drive our cars aggressively, clumsily, unsafely and intoxicated. We screech away at green lights, speed, text behind the wheel and brake at the last minute. We maintain our vehicles poorly, idle excessively, and drive when and where we want whether the roads are congested or not. We use them to kill 1.3 million people each year – some 40,000 in North America annually.

**We always buy big.** We tend to buy vehicles powerful enough or large enough for our 99th percentile requirement. If someone expects to haul a boat to and from the cottage once a year, he is likely to get a vehicle with the power to do that, then drive it in the city, outsized and overpowered for the other 350 days of the year. Similarly, report author Bern Grush, drives alone about 6,000 km per year, has one passenger for about 3,000 km and more than one for perhaps 300 annual km. He did not buy a two-passenger vehicle, even though that would serve well for 95 per cent his VKT; instead, he purchased a vehicle significantly larger than his average requirement. Collaborating author John Niles has never had more than two people in his car, and makes all of his trips with an empty back seat with room for three. The same thing happens with business or vacation rentals for just about everyone. When you rent a vehicle on a business or vacation trip, even when you will be alone for the entire rental period, you rent a five-passenger sedan, usually for lack of options. How often have you heard: "We don't have the economy model you've requested, miss, would you like a free upgrade to a full-size vehicle?"

**Our vehicles run under-capacity.** This is a corollary to "Buying Big" and matches "the city-bus problem." The reason we see so many single occupant vehicles is the same reason we so often see large, lumbering buses with only seven passengers. One of the accusations frequently leveled against the car in developed countries is the "1.2 occupant, five-passenger vehicle." This is a fundamental outcome of purchasing a fixed-sized vehicle for variable-sized group travel. When the 1.2-occupant vehicle is criticized as a reason to use transit, the same problem holds. Using a five-passenger vehicle to carry one person means 20% occupancy. Using a 50-passenger bus carrying 10 people is also at 20% occupancy. The advantage of a bus is to use less lane space per commuter during peak hours. Unfortunately, the bus voids its peak-hour environmental advantage when it operates largely empty during off-peak hours. But you need to maintain the bus routes: those with too few vehicles are not well patronized, just as those with too many run empty. This lack of flexibility limits ridership numbers in many cities.

**We pay too soon.** Once we own a motorized vehicle with a purchase price that is inflated and front-end loaded with payments, taxes and fees, our mobility preferences necessarily become locked in. Our willingness to walk more than very short distances is diminished, and our interest in transit is extinguished. After all, we have made a large investment in our vehicles. If we had bikes before, they will become nests for arachnids. If we live downtown, we are more likely to consider moving a little farther out where there are more trees and some room for kids. If we were satisfied with local entertainment and restaurants before, we will now venture more often to farther venues – our car will have increased our Marchetti radius. Because a large portion of the expense of an automobile occurs up front when it is purchased or in fixed monthly payments and the variable portion such as gas and parking is smaller and distributed, we see our vehicle as paid for and the marginal cost of the next mile as low or near-zero. All in, the average car mile in North America costs about 90 cents. Why are so many of us willing to idle our overlarge and overpowerful vehicles for 15 or 20 minutes on hot or cold days for a little comfort? Because on the margin, that comfort is nearly free, and it is perceived that way. Ownership lowers visible access costs; lower perceived cost increases consumption.

**Once in, we're stuck.** The more one pays up front for a vehicle, the more one's inner "economic man" must drive it to recover that investment. To pay a high price for a personal vehicle that may then be used quite cheaply on the margin is not a formula for a bike-transit-walk-carshare life style. Since many prefer to own a personal vehicle, our tax policies defeat us before we even start. Our tax policies help lock in congestion, pollution, obesity, oil consumption and national security risks.[115] While it is true that making vehicle purchases more expensive means that fewer will be purchased – the larger effect is that fewer new ones will be purchased by lower-income families, forcing these families to buy or keep vehicles that tend to pollute more.[116]

## 10.2 What difference could reducing household vehicle ownership make?

The doubling time for our current world vehicle fleet population is approximately 20 years.[117] Assuming this implies an equivalent doubling time for worldwide PKT, what difference could be made if we satisfied the implied quadrupling of PKT demand (2010-2050) with a lower world vehicle population than extant in 2010?

The emerging technology of automated vehicles offers an enabler that could help reduce car ownership to 20% of its projected 2050 level of four billion vehicles (i.e., 80% of the 2010 vehicle population). This would be a critical and likely indispensable advantage in addressing the problem of environmental sustainability and urban livability.

The robotization of motorized vehicles has value independent of whether these vehicles are shared. Sharing is neither a given nor a necessity for market success. Furthermore, vehicle robotics are part of a broader mobility digitization spectrum and will not unfold in isolation. What would happen if, by 2050, vehicles were emission-free, fully automated and if household ownership was near-universally replaced with shared fleets? As an exercise, let's examine these three features layered progressively against a base of business-as-usual: our current world fleet, internal combustion engine, semi-automated (only), personally owned after two projected doublings to four billion vehicles 2010-2050.

When concerned about the footprint of fossil-fuel vehicles, we primarily focus on the tailpipe: $CO_2$, chemical pollutants and particulates. In general, only 50% of the total direct footprint of a motorized vehicle is its tailpipe contribution. A second portion, the other 50%, is in its manufacture and maintenance (mostly manufacture).[118] Hence, if we were to make all vehicles 100% emission-free (100% renewables, emitting only water), we'd cut the problem in half – but only if our vehicle population stayed constant, which is not what is projected.

Imagine in 20 years when the world vehicle population doubles (highly likely) and all vehicles are squeaky-clean (unlikely), we might hope to have at least broken even. We would have traded one billion dirty cars for two billion clean ones. Then the entire footprint would be in manufacturing and maintenance and none in operation.

Not quite: there is a third component. It turns out that the value of all parking infrastructure (in the U.S., at least) is equivalent to the total value of all the motorized vehicles (in the U.S.[119]). Actually, its worse, but I rounded down to be conservative. I further simplify by equating the total environmental harm caused by parking and parking infrastructure to be equivalent to that of today's tailpipe emissions. The harm from parking is likely greater; it simply does not all exhibit as GHGs or air-pollution, although most does so indirectly.

There is a fourth component: the environmental cost of the world's road, bridge and tunnel infrastructure. It effects are numerous and complex and they do harm in yet different ways, but I give them the same conservative weight – even while we continue to build – just to be sure not to overestimate the harm.

Lastly, there is a fifth element: the cost to the environment of 1.3 million (and growing) road deaths and a far greater number of grievous injuries each year, could again be considered, for simplicity, an equal environmental burden matching each of the previous four harms.

Hence, if we were to quadruple the 2010 world vehicle population by 2050 and we commit to zero tailpipe emissions,[120] we will have diminished the 2050 problem (slated to become 400% worse if nothing changes) by 20%. In other words, the environmental problems contributed by motorized surface transportation would be 320% (rather than 400%) worse than now.

Such back-of-the envelope reckoning is crude, but I have been conservative. To complete this exercise, how might some assumptions play out?

**Base scenario.** This is a business-as-usual scenario, using only semi-automated vehicles – except that vehicle population quadruples. In this case, the total problem increases 400%, a simple linear assumption. As a consideration, consumption usually seems to make things worse exponentially, but innovation sometimes makes them better disruptively or, conversely, compounds consumption,[121] so a linear assumption is both neutral and naive. But it is a safe starting point.

**Clean scenario.** Add to the Base scenario a worldwide conversion to zero-emission vehicles. Include zero-emission power-generation. This is not likely by 2050. But let's include it, here, as a first approximation. In the Clean scenario, vehicle manufacturing, parking, roads and road building, and road carnage continue linearly with vehicle population (another simplifying first approximation).

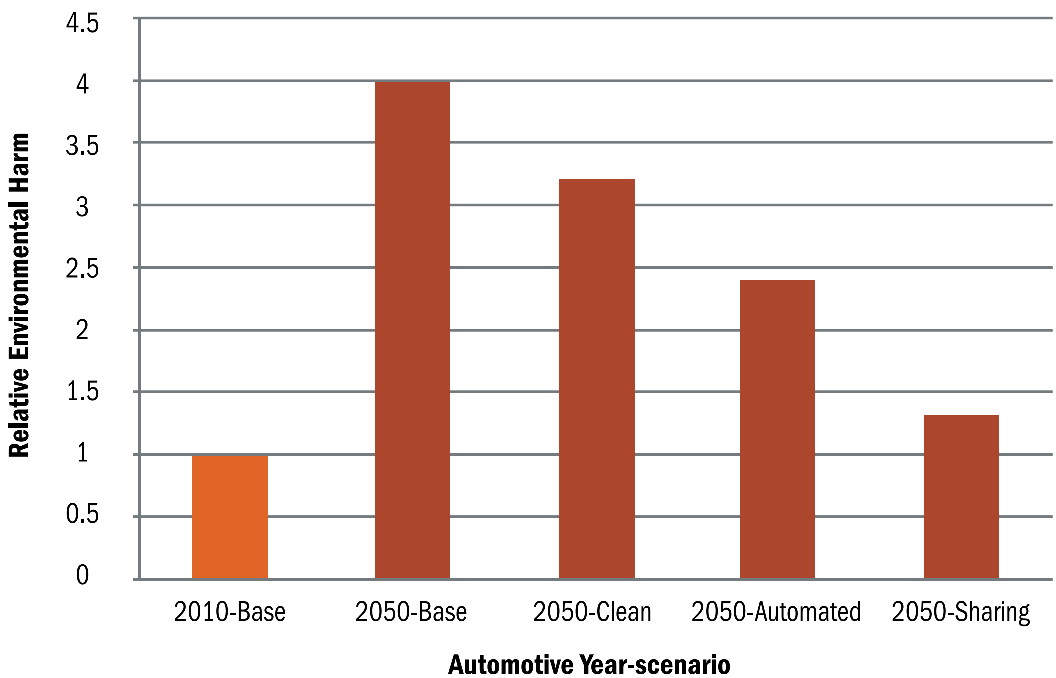
**Automated scenario.** Add to the Clean scenario that by 2050 the only sorts of vehicles available are fully automated, that there is not a single driver left anywhere except on movie sets and that road carnage drops to zero (a minor exaggeration as a first approximation) while manufacturing, parking, and roads and road-building continue linearly (also a simplification).

**Sharing scenario.** Add to the Automated scenario that by 2050 the universal way to access a motorized vehicle is via TNCs that provide only automated vehicles, and that the total worldwide quadrupled PKT demand can be satisfied with the 2010 vehicle count. Manufacturing would tick upward a bit faster from the extra wear due to the tragedy of the commons) and tick down a bit (fleet optimizations related to scale and automated distribution) so I simplistically assume manufacturing continues linear growth matching the PKT demands, i.e., 400% of 2010 output. I assumed a parking drop to 50% from now since the same number of cars need less parking, but we still want to reduce deadheading so we'll keep a lot of parking around for off-peak parking. I assume we can also reduce the road footprint by half of base (i.e., 200% instead of 400%) since sharing makes many road-use, scheduling and navigation optimizations possible.

The grossly simplified assumptions I have made to generate Figure 9 are imaginable but unlikely in the time frame. But this is the direction we want to be headed: zero-emissions, automated and shared. Furthermore, there are many other elements of optimization – especially materials, additive manufacturing and tailoring (right-sizing) – that would enable further footprint reduction. Without a full, systems approach to addressing the demands of automobility the introduction of vehicle automation is unlikely to reduce our current environmental and livability burden of automobility. Rather, at best it will merely slow down the rate at which these burdens will get worse.

**Figure 9:** **The relative, virtuous effects of electrification, automation and sharing on the environment**

The Base (business-as-usual) scenario assumes a 20-year doubling time with linear growth in harm to the environment and urban livability. A Clean scenario means all things remain the same, except all energy comes from renewable resources and produces zero-emissions. The Automated scenario adds automation (and connectivity) to the Clean scenario and the Sharing scenario adds 100% non-ownership to the Automated scenario. (The y-axis is the relative environmental and livability cost. The 2010 Base is set to 1.)




Hence, even while my assumptions are simplifications, there are many other pending potential changes and technologies that when realized could make it possible that the global footprint of surface transportation in 2050 need not be worse than it is today. Programs to ensure massive fleets of robotic taxis and shuttles, such as Transit Leap,[122] are designed and managed in a way to shift from 80% to 20% household vehicle ownership over 40 years are important ingredients.

# 11.0 CONCLUSION

**The gathering speed of mobility digitization – ride sourcing, MaaS, vehicle automation and connectivity – is catching us off guard. Innovation moves more swiftly than government; bits move faster than concrete and steel.**

Digitization carries hopeful potential to assist cities and regions to better cope with the demands of travellers while addressing the outsized footprint and inefficiencies of transportation, but it also carries the seeds of disruption that our transit authorities (and our transportation planners) both need and fear. It is likely that the recent history of disruption in the taxi industry is a tiny microcosm of the coming disruption of transit, and that few transit authorities will be sufficiently nimble to collaborate.

The current fever of hype and expectation for the technology of vehicle automation makes matters worse as we too-seldom distinguish between the impending household market of exciting consumer-oriented semi-automated vehicles and the slightly more distant market for currently plodding, fully automated, public-service vehicles. The attention-getting semi-automated vehicle, falsely described as a driverless vehicle,[123] makes a sober understanding of these two markets harder to achieve. We are at risk of concurrently being fooled by hype and missing the real opportunity for cities.

We humans consume the type and quantity of automobility that pleases us in the short run; we have so far proven ourselves to be unlikely, if not unable, to consume intelligently in order to reduce carbon, congestion or carnage unless the choices offered also provide the personal mobility we desire.[124] Ontario's providers of regional transportation systems and infrastructure face fundamental constraints:

- There is no satisfactory substitute for independent, responsive automobility.
- There is no quenching of human preference for powered mobility.
- There is no avoiding human distraction.
- There is no turning back from vehicle automation.
- Vehicles that are privately owned – because they are used so little and parked so often – generate two or three times the environmental and livability harm (direct and indirect) compared to vehicles that can be use-shared or ride-shared.
- Vehicle automation – however important – is only an enabler and multiplier of other automobility attributes that need to be managed as a package toward a desirable systems solution: convenience, speed, cost, availability, and scalability.
- For the last 120 years, the nature of the pre-digital technology that provides automobility means that human preference for individualized and personally optimized mobility service has been inextricably bound to vehicle ownership.

It is not fully understood to what degree mobility digitalization (including full vehicle automation) can break this bond between our fundamental need for automobility and its expression in vehicle ownership. What evidence we do have has been gathered in a world without automated vehicles. This provides us only with evidence from transit, car shares and ride sourcing, all of which correlates negatively with personal wealth and pale in volume to household ownership. If there is a way to break that bond it would only come about by offering something better, attainable and scalable. The coming robotic fleets, if they are to do what we expect of them, cannot look and behave as do taxis and transit today.

Stacked against this challenge is a century-old industry with skilled designers and savvy marketers who have a deep and experienced understanding of human foibles and preferences for automobility. The world automobile industry can design something this year, make it next year, and sell it into targeted household consumer segments the year after (Section 7). Our current government transit offerings cannot compete against this:[125] these governments and authorities often cannot complete a plan of significant heft before a new mandate changes its schedule, reduces its deliverable or cancels it altogether.[126]

The difference between the incremental, Feature-Creep model for semi-automation now being pursued by Mercedes, Nissan and Tesla and the disruptive model of removing the driver completely as pursued by Easy Mile, Google, Navya and Uber holds the key to the solution we espouse.[127] There are numerous safety, operational and cost problems with mixing fully and semi-automated vehicles at any ratio – whether 1% or 99%. Following an incremental, gradual, mixed-traffic model will lead to years of contention regarding traffic rules, overly cautious robots, insurance liability, and new legions of distracted drivers using automation that operates most but not all of the time.

If the GTHA focused on full-solution, spatially constrained, robo-transit and robo-taxi innovation rather than preparing and waiting for household vehicle Feature-Creep, we could introduce less contentious, incremental improvements in controlled circumstances. We would only need to prepare and maintain the area-limited infrastructure needed as the GTHA builds out robo-transit and robo-taxi networks prescribed by Transit Leap. We would bite off what we could chew.

If we devised business and financing models to grow PKT exponentially in shared, safe and reliable public-service vehicles and in ways that allow for labour redeployment instead of job losses, we could reduce the subsidy burden of transit, grow its ridership, draw drivers out of household vehicles, and increase transportation job counts in the same way TNCs do now. Transit Leap gradually minimizes vehicle ownership in stages toward 20% of current levels while gradually increasing public-service transportation-related employment levels (including job description changes), as it targets 80% of PKT in use-share and ride-share vehicles.

Rather than resisted, TNC ride-hailing should be groomed, regulated and integrated into a new hybrid solution of privately operated fleets governed for access and equity. It is currently the case that however much Lyft and Uber may be good for young, mobile, carless travellers in our cities, TNC services, so far, are not designed to be available to the poorest or unbanked travellers.

The next stage of mobility digitization, MaaS, is now ready for deployment. This enables further service aggregation that can penetrate to more classes of travellers including more marginal car owners[128] and more of the unbanked or those without credit cards. MaaS also provides a new handle on ways to promote transportation equity while providing fewer heavy transit vehicles per PKT.

Municipal governments have a critical role to ensure job access and transportation equity even as current transit is disrupted. As automation sets in with multiple service levels related to things such as ride features, number of stops, vehicle age, ride sharing, convenience, comfort and more, a range of prices can be supported to be affordable across the entire spectrum of users. Both Uber and Lyft have already started to teach us how to segment publicly available transportation by price and demand. There are ways – with far less subsidization than common now – to have sustainable transportation available to everyone at a level affordable for each. This is a preferred future.

The growing struggle for public transit to cope, much less thrive, in the face of rapid, digital change will require private industry financing, planning and coherence to bring the GTHA to the meaningful execution needed to transform the ownership-automobility bond. But Ontario should still be expected to lead creatively and boldly in shaping the new paradigm.[129]

The competition between vehicle ownership and vehicle sharing (taxi, transit, car share) has, until now, been decisively dominated by ownership. Infrastructure and urban form are not only shaped by the automobile, they are further distorted and decisively locked in by personal ownership. It behooves us to satisfy our needs for motorized automobility in a way that dramatically reduces ownership.

There is no way to guess all of the effects mobility digitization will have on the future of urban spatial distribution: density and sprawl. The harder truth is that what we believe we are able to predict about these new technologies is less important than what we don't know or have not yet imagined. The things we surmise now about safety, productivity and labour disruption or the things we hope about congestion, energy efficiency and parking space recovery are easy enough to envision. But there are many other things such as how we will locate ourselves in this re-enabled landscape, how transportation business and equity models will change or could be regulated and nurtured, how we will manage land use, and how we will think about and finance the infrastructure needed to hold all this together, that are much harder to contemplate.

And these things also need our attention. Starting now.

# ENDNOTES

1 Grush, B. (2011) Disappearing Act, Traffic Technology International, October/November.

2 Shladover, S. (2016) What "Self-Driving" Cars Will Really Look Like, Scientific American, June.

3 Early starts with near-robo fleets (Uber in Pittsburgh and nuTonomy in Singapore) are using Level 3 vehicles with drivers in attendance. While positioning toward fully robotic fleets, robo-taxi operators will need human attendants for some time and when permitted to operate without human assistants, will be constrained for speed as well as permitted routes and areas.

4 Throughout this report, it is noted that new regulations will likely be needed, but I make no concrete suggestions in the text. It will be appropriate to encourage the use of massive, shared public service fleets, ensure that access to those fleets be socially equitable and accessible, operationally efficient and safe, and that the expected and critical role of SMPs is designed to prevent cherry-picking of routes and customers as has already happened with TNC operators. Specifically, while private providers and SMPs may offer a variety of services to serve many demographics and geographies, on the whole everyone must have at least basic access to transportation for jobs, shopping, family, school, entertainment and worship. A key purpose for such regulation (besides reducing the fleet of privately owned vehicles) is to ensure that in 2035 the gap between service by transit and a household vehicle is only a fraction of what it was in 2015.

5 SMPs are both important and require caution. See sections 9.3 and 9.3.1. The nature of SMPs assumed here is in the form of commercial partnerships that support service delivery, including the funding and operation of fleet vehicles.

6 Behavioural Economics plays an important and often ignored role, here. https://www.behavioraleconomics.com/the-behavioral-economics-guide-2016/

7 Grush, B., Niles, J. (2016) How cities can use autonomous vehicles to increase transit ridership and reduce household ownership, Joint Conference of the Canadian Transportation Research Forum and the Transportation Research Forum.

8 Grush (2011).

9 Sperling, D., Gordon, D. (2009) Two Billion Cars.

10 Davis, S., Diegel, S., Boundy, R. (2015) Transportation Energy Data Book, Edition 34, U.S. Dept. of Energy, p. 3-15.

11 Dargay, J., Gately, D., and Sommer, M. (2007) Vehicle Ownership and Income Growth, Worldwide: 1960-2030.

12 Poole, R. (2016) Surface Transportation News #155. http://reason.org/news/show/surface-transportation-news-155#e

13 Ronald Bailey (End of Doom referenced below) carelessly used robo-fleet simulation data that suffers from similar faults as described by Poole to help wave off concerns for the environmental difficulties we may be in.

14 This range corresponds to the 2009 founding of Uber and the Roland-Berger prediction of 27% of world PKT by robo-taxi by 2030 (see Bernhart footnote, below). But this period will compromise far more than those bookends.

**15** Fenn, M. (2016) "Megatrends: The Impact of Infrastructure on Ontario's and Canada's Future," an independent study prepared for the Residential and Civil Construction Alliance of Ontario (RCCAO).

**16** Fenn, M., personal communication, August 2016.

**17** If GO and automated vehicles make commuting less unpleasant and less costly, the pattern of out-migration will resume. Over three million people have chosen a suburban ground-related home in the GTHA, and that's because they had a choice. Denying them an affordable choice through land-use policy can only constrain that impulse until there are economic and electoral consequences. Bottom line? We will likely see a flattening of our cities, as well as a resurgence of cities well beyond the current shadow of the GTHA commuter-shed, whose single-family home and business costs are now routinely half those of Toronto and Ottawa (M. Fenn, personal communication, August 2016).

**18** CityMobil2 (2015) D27.2 "Results on the on-line DELPHI survey."

**19** Given an expectation of 27 trillion VKT worldwide in 2021 and a 2% annual growth rate in VKT, the planet will experience a cumulative 1.6 quadrillion VKT by 2060. Given automation, we should expect an even higher number.

**20** Shladover (2016).

**21** Teller, A. (2015) https://backchannel.com/how-to-make-moonshots-65845011a277

**22** For the purposes of this report, we simplify our taxonomy to semi-automated and fully automated; i.e., driver-in or driver-out.

**23** SAE International, "Levels of Automation for On-Road Vehicles," http://www.sae.org/misc/pdfs/automated_driving.pdf

**24** Bernhart, W., Winterhoff, M., Hasenberg, J., and Fazel, L. (2016) (R)evolution of the automotive ecosystem. Roland Berger. Munich.

**25** Shladover (2016).

**26** Shladover (2016).

**27** Fenn (2016).

**28** Musk, E. (2016) "Master Plan, Part Deux." https://www.tesla.com/en_CA/blog/master-plan-part-deux

**29** CityMobil2 (2015).

**30** Bernhart et al. (2016).

**31** Winterhoff, M. Roland Berger, personal communication, April 2016

**32** The growth and infrastructure demand will not be evenly distributed; the pertinent question is how much and what kind will be needed in Ontario?

**33** Bernhart et al. (2016).

**34** https://news.ontario.ca/mto/en/2015/10/ontario-first-to-test-automated-vehicles-on-roads-in-canada.html

**35** https://www.thestar.com/autos/2016/07/22/autonomous-vehicles-are-closer-than-you-think.html

**36** Wired (2016) "Ford Says It'll Have a Fleet of Fully Autonomous Cars in Just 5 Years." https://www.wired.com/2016/08/ford-autonomous-vehicles-2021/

**37** Metrolinx (2016) "Discussion Paper for the Next Regional Transportation Plan (GTHA)." August.

**38** Hussain, S., Schulich School of Business, personal communication, September 2016.

**39** Keller, M. (2016) "Who Owns the Cars? The Billion Dollar Problem with Autonomous Taxis." https://www.linkedin.com/pulse/who-owns-cars-move-autonomous-vehicle-ride-sharing-maryann-keller

**40** https://www.cbinsights.com/blog/driverless-shuttle-companies/

**41** Babcock Ranch Automated Vehicle Project: Request for Interest (RFI) (July 2016).

**42** This distinction between semi-automated and fully automated vehicles is a simplification of the several levels of the SAE standard levels of vehicle automation. For our purposes, any form of automation that requires an operator within the vehicle in attendance is semi-automated, not permitted to be operated on a roadway without a licensed driver aboard the vehicle and in control. When the presence of a driver is not required, the vehicle is by definition fully automated – even if the vehicle is range-limited (geo-fenced). This can also include some oversight or even operational control by remote operators, which is the case with flying drones. When a semi-automated vehicle is switched to an "auto-drive" mode, but the presence of a driver is still required—even if that driver might attend to other activities while in the driver's seat—that vehicle is still a semi-automated vehicle. Sometimes a fully automated vehicle may be severely restricted in its permissible operating range (such as the minibuses already being deployed in very limited environments and at low speeds). Such range-limited vehicles would be considered "Level 4" in the SAE spectrum, but in this report, we simplify our taxonomy to semi-automated and fully automated – i.e., driver-in or driver-out.

**43** Ditta, S., Urban. M.C., and Johal, S. (2016) "Sharing the Road: The Promise and Perils of Shared Mobility in the GTHA." The Mowat Centre. p. 38, provides a superb, projected, example of this: "after a protracted legal battle, UberHop and Lyft Line were found to be infringing on the TTC's transit monopoly. This ruling lost most of its force the day it was handed down, however, as both companies immediately shifted their services from fixed routes to dynamic routing – thereby escaping legal categorization as transit services."

**44** http://www.bizjournals.com/columbus/news/2016/06/21/breaking-columbus-beats-six-other-cities-to-win.html

**45** CityMobil2 (2015).

**46** Kovacs, P. (2016) "Automated Vehicles: Implications for the Insurance Industry in Canada." Insurance Institute of Canada.

**47** http://www.caranddriver.com/features/semi-autonomous-cars-compared-tesla-vs-bmw-mercedes-and-infiniti-feature (In 2015, Tesla released an early (beta) version of a semi-automated product it calls Autopilot. By mid-2016, it disengages frequently and is not yet reliable (or recommended) for hands-off driving.)

**48** Bernhart et al. (2016).

49 Dargay, J., Gately, D., and Sommer, M. (2007) "Vehicle Ownership and Income Growth, Worldwide: 1960-2030."

50 Nieuwenhuijsen, J. (2015) Diffusion of Automated Vehicles: A quantitative method to model the diffusion of automated vehicles with system dynamics. (Masters Thesis, Delft University of Technology).

51 Arbesman, S. (2016) "Overcomplicated: Technology at the limits of comprehension."

52 Burns, L., Jordan, W., Scarborough, B. (2013) "Transforming Personal Mobility," The Earth Institute, Columbia University.

53 Fagnant D., Kockleman K. (2015) "Dynamic Ride-Sharing And Optimal Fleet Sizing For A System Of Shared Autonomous Vehicles, TRB." http://www.ce.utexas.edu/prof/kockelman/public_html/TRB15SAVswithDRSinAustin.pdf

54 Marchetti, C. (1994) "Anthropological Invariants in Travel Behaviour, Technological Forecasting and Social Change," p. 47, 75-88.

55 The authors of the Roland Berger report used an estimate of 23 trillion worldwide VKT for 2015 to increase by 35% by 2030, hence 0.27 x 23 x 1.35 = 8.5T VKT (personal communication with one of the authors, April 2016).

56 Massive technology transitions often move at radically different paces and in different directions. South Africa and India adopted cell phones rather than building traditional landline networks. Post-war Germany, South Korea, Japan and Taiwan were able to skip a generation of infrastructure. Robo-taxis are likely to be adopted in countries such as China far more rapidly than here. Because transportation of people and goods is so effectively connected to economic growth, and because automated vehicles are expected to reduce costs between 60-80%, this will further close the wealth gap between developing and developed world. Automated transportation is an enabler, not an end to itself. To be focused primarily on vehicle testing is a poor strategy for government.

57 It would be naive to suggest that we should not engage in road testing. Such testing can create awareness, generate debate about deployment, and focus regulators on rule changing that may be needed. But this cannot be a sufficient response from the province, and to date our engagement with vehicle automation has been anemic. We are wallflowers.

58 E.g., Jamais Cascio, futurist and senior fellow at the Institute for Ethics and Emerging Technologies, quoted in http://www.businessinsider.com/why-no-one-will-own-a-car-in-25-years-2015-6

59 Shladover (2016).

60 Bailey, R. (2015) "The End of Doom, Environmental Renewal in the Twenty-First Century."

61 Nieuwenhuijsen (2015).

62 Shladover (2016).

63 This descriptive system-change model and much of the discussion in this section was contributed by Edgar Baum, the Chief Brand Economist at Strata Insights and Lecturer on the Finance of Brand Management at the University of Toronto.

**64** media2.planning.org/media/npc2016/presentation/s507.pdf

**65** Dargay (2007).

**66** We have substantial experience with unmitigated demand in innumerable urban environments where the built limits for vehicle traffic have been substantially exceeded: The Gardiner in Toronto, Lakeshore Drive in Chicago, crosstown arteries in NYC. The impact of exceeding roadway carrying limits are not linear; rather they exhibit both an exponential and a highly volatile impact that results in an increasing incidence of logarithmic growth in congestion for short periods and travel estimates by even the most sophisticated mapping models from Google and others being wrong by wide margins.

**67** According to http://mutcd.fhwa.dot.gov/knowledge/faqs/faq_part4.htm#tcsgq3 there likely more than 300,000 signalized intersections in the U.S. Guessing that this is only 10% of all intersections and throwing in Canada, one imagines there might be some 3.3M intersections in total. We need address all of these in some way. Likely, Elon Musk would suggest that cars would simply learn this map from shared, automated driving experience. Perhaps.

**68** To our knowledge, no one has yet died from using printer fonts.

**69** Grush, B., Niles, J. (2015) "What Gartner's Technology Hype Cycle teaches us about the Autonomous Vehicle. Thinking Highways."

**70** Maheshri, V., Winston, C. (2015) "Did the Great Recession keep bad drivers off the road?" Journal of Risk Uncertainty. p. 24.

**71** It is amusing to consider that the thing people most remarked on after their first experience of the automobile 120 years ago was that it did not have a horse standing in front of it. How long now has it been since the horselessness of an automobile has been noted?

**72** The authors of the Roland Berger report (27% PKT in robo-taxis by 2030), made similar numeric projections without disclosing that the absolute congestion/infrastructure problem would likely get worse.

**73** The ECAN model – and much of the next two sections – was developed by Edgar Baum.

**74** This figure and its caption is courtesy of Edgar Baum.

**75** Musk, E. (2006 and 2016) https://www.tesla.com/en_CA/blog/master-plan-part-deux

**76** Marchetti calculated 13% of after-tax income as a travel budget. Taking median family income for Ontario at $79,000 (http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil108a-eng.htm), and assuming 75% remains after taxes, Marchetti suggests our average annual travel budget would be 13% x 75% x $79,000 or $7,700. If that were to be spent on exclusively automobile use that matches very closely the Canadian annual average total cost of ownership for a mid-range sedan (http://www.caa.ca/wp-content/uploads/2012/06/CAA_Driving_Cost_English_2013_web.pdf)

**77** We are critical of Tesla using the term "autopilot" for its current (2016) automation technology.

**78** We have not yet seen a workable proposal to solve the attention problem for semi-automated vehicles. Some think, and we agree, that the driver cannot be relied on and only full automation will address the human attention problem. This is one of the key differences between the two technologies that provides full automation with a consumer advantage. Here is a useful reference: http://thinkinghighways.com/distracted-driving-is-the-focus-for-university-of-washington-researcher/

**79** As of August 2016, Ford announced 2021 for its first robo-taxi release (gosh, is 2021 the "5-year hedge date" again?).

**80** Kahneman, D. (2011) "Thinking Fast and Slow."

**81** The argument against the viability of fully automated household vehicles was made in Section 6.2.

**82** Teller (2015).

**83** Burns et al. (2013).

**84** Marchetti (1994).

**85** Shoup, D. (2004) "The High Cost of Free Parking," American Planning Association.

**86** http://www.citylab.com/commute/2015/07/the-clearest-explanation-yet-for-why-millennials-are-driving-less/398366/

**87** http://www.citylab.com/tech/2015/01/how-driverless-cars-could-make-traffic-dramatically-worse/384821/ http://www.fastcoexist.com/3058724/how-autonomous-cars-could-lead-to-even-worse-traffic

**88** Davies, A. (2015) "Ford's Skipping the Trickiest Thing About Self-Driving Cars," Wired, https://www.wired.com/2015/11/ford-self-driving-car-plan-google/

**89** Teller (2015).

**90** Kovacs, P. (2016) "Automated Vehicles: Implications for the Insurance Industry in Canada," Report to the Insurance Institute of Canada. In this report several uncertainties were recognized by as barriers to being able to describe lower insurance premiums until a significant actuarial history is accumulated. Hence, the early automotive industry promise of a significant reduction in premiums was premature.

**91** MaaS brings together all means of travel combining options from different transport providers into a single planning, reservation and payment app on your smartphone. This removes the hassle of multimodal trips. See https://maas.global/

**92** Alessandrini, A., (2016) https://www.youtube.com/watch?v=PUr8ljfb2Cg CityMobil2 Project Coordinator, U of Florence.

**93** http://www.citymobil2.eu/en/About-CityMobil2/Overview/

**94** Citymobil2. Also see: CityMobil2 (2015) D27.2 Results on the on-line DELPHI survey

**95** Amditis, A. (2016) https://www.youtube.com/watch?v=PUr8ljfb2Cg Research Director ICCS.

**96** Alessandrini (2016).

**97** Mercier-Handisyde, P. (2016) https://www.youtube.com/watch?v=PUr8ljfb2Cg Citymobil2 Project Officer, European Commission, DG Research & Innovation.

**98** Alessandrini, A., personal communication, August 2016.

**99** Extra sensors were added to help mixing with other traffic: eight cameras, a scanner and a deep learning system to learn the patterns/behaviour of different types of people and vehicles it will encounter. Their goal is to be able to drive empty eventually.

**100** This information is partly from the WEPod webpage and partly from personal communication with, Marieke Kassenberg, September 2016.

**101** Burns et al. (2013).

**102** Although, this was not discussed in the Burns study, daily user interactions with shared vehicles and a reduced need for some community members to travel outside this large community every day would provide an opportunity for a shared fleet of semi-autonomous vehicles for external trips. As an example, a further halving of the household fleet and a concurrent doubling of the shared fleet would mean a per capita vehicle population rate of 0.34. The current world vehicle per capita rate is 0.16 and growing toward a natural saturation of 0.7 or 0.8 (i.e., seven or eight billion vehicles after we peak at 11B people in 2100 (Dargay et al.,2007). Approaches such as Kitson's, if spread to other communities, worldwide would help lower that saturation level.

**103** http://endofdriving.org/wp-content/uploads/2016/08/Babcock-Ranch-Automated-Vehicle-Project-RFI.pdf

**104** Tapscott, D. (2016) "Blockchain Revolution."

**105** Sweet, M., Harrison, C., Kanaroglou, P. (2015) "Congestion Trends in the City of Toronto (2011-2014)," McMaster University.

**106** Fenn (2016).

**107** 1 hour x 365 days x 60 years.

**108** This is an example of the Logistics Commons described in: Rifkin, J. (2014) "The Zero Marginal Cost Society," p. 264.

**109** As an example, a Leap 5 fleet size for the GTHA that serviced 80% of the PKT would range between 500,000 and 900,000 vehicles depending on the size distribution between two-seater, four-seater, six-seater and 10-seater vehicles. Such a fleet would have vehicles of varying "status" quality available at varying prices – just car rentals do now.

**110** A preview of this is visible in cities such as San Francisco, Atlanta, Philadelphia, Dallas, Cincinnati, Pittsburgh and others: http://www.theverge.com/2016/9/1/12735666/uber-altamonte-springs-fl-public-transportation-taxi-system

**111** Ditta, S. p. 37 (This is one of two future scenarios Ditta et al. set in 2020) (2016).

**112** Sections 9.3 and 9.3.1 were considerably improved after personal communication with Michael Fenn, August 2016.

**113** A very useful discussion re: P3s is here: McKellar, J. and Hussain, S. (2012) "Discussion Paper Prepared for the National Executive Forum on Public Property," National Symposium, Vancouver, May 2012.

**114** The travel radius achievable in our daily hour time budget, influenced by our city's congestion and the means of mobility we can afford.

**115** Front-end loading of taxes and fees (compared to road-use charges) helps lock in congestion. We pay for automotive transportation via vehicles sales taxes, licence fees, fuel tax, tire taxes and pre-paid insurance. Mostly paying for our automobile and all of its taxes and fees more toward the beginning of our ownership relationship, means that the marginal additional cost of the next mile is a tiny and diminishing fraction of its actual cost. The perceived cost of the "next mile" is far lower than its true cost.

**116** Dennis DesRosiers has for years pointed to the pollution (GHG and particulates) effects of keeping old cars too long. DesRosiers, D. (2007) Trends in vehicle longevity, Observations 21:21 November 15.

**117** These are global numbers. U.S. numbers appear to have slowed, even saturated on a per capita basis. Canadian numbers are still growing at 2% (Statistics Canada). Current doubling time is closer to 30 years in Canada.

**118** Mike Berners-Lee, M. (2011) "How bad are bananas: The carbon footprint of everything."

**119** Shoup, D. (2004) "The High Cost of Free Parking," American Planning Association.

**120** Sperling, D., Gordon, D. (2009) "Two Billion Cars."

**121** Jevons Paradox. If you make it better, cheaper, easier, faster, more will be consumed.

**122** Grush, B., Niles, J. (2016) How cities can use autonomous vehicles to increase transit ridership and reduce household ownership. (2016) Joint Conference of the Canadian Transportation Research Forum and the Transportation Research Forum. (http://endofdriving.org/wp-content/uploads/2016/02/How-cities-can-use-AVs.pdf)

**123** For example, by Volvo in Stockholm and Uber in Pittsburgh.

**124** Thaler, R., Sunstein, C. (2008) "Nudge: Improving Decisions About Health, Wealth, and Happiness."

**125** To add insult to injury, Ontario is expected to build unpriced road infrastructure to carry vehicles built by private industry and used by private households paid on a model of declining fuel-tax revenue.

**126** This had been repeated may times over the past few decades in the GTHA.

**127** Some makers, notably Ford and Volvo, will likely make vehicles for both the semi-automated and fully automated markets; Volvo just announced a fully automated vehicle by 2021 in partnership with Uber.

**128** Households that have an underused vehicle and would own one fewer vehicle given sufficiently responsive MaaS.

**129** TransLink (2016) "The Future of Driving: Policy Directions for Automated Vehicles and New Mobility Services in Metro Vancouver."

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