

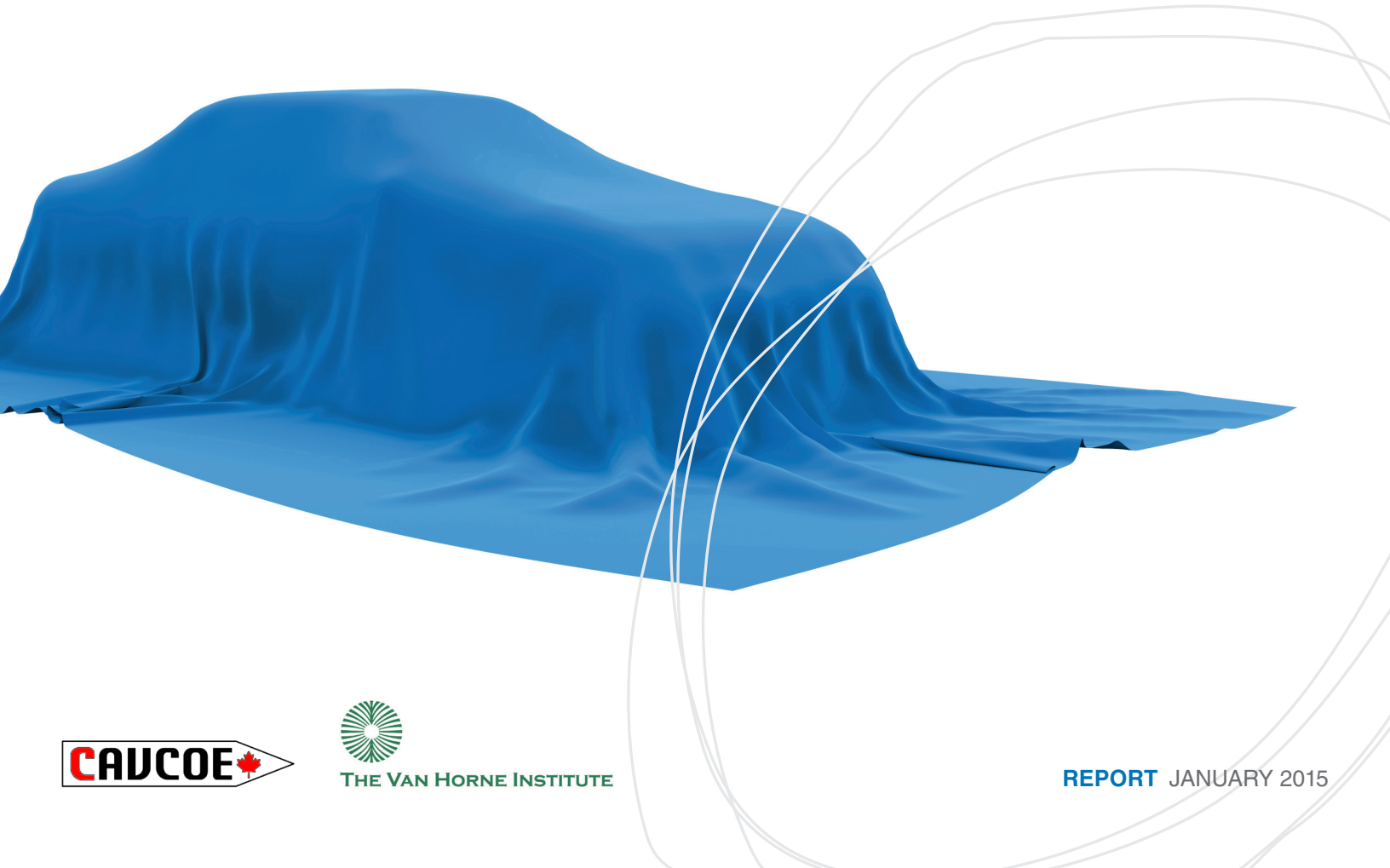


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Automated Vehicles.

The Coming of the Next Disruptive Technology



THE VAN HORNE INSTITUTE

REPORT JANUARY 2015

Automated Vehicles: The Coming of the Next Disruptive Technology

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Preface

Automated vehicles (AVs) are, in some forms, already here. If history is a guide, their rollout may occur rapidly. They have the potential to bring great benefits, particularly in the form of saving us time and reducing the number of collisions on our roads. But as they roll out, they will be disruptive to both the public and private sector in the process. Governments and businesses must begin to plan for the arrival of AVs sooner, rather than later. This report provides an overview of the potential benefits of AVs and highlights some of the issues that we need to start planning for.

To cite this report:

Gill, Vijay, Barrie Kirk, Paul Godsmark, and Brian Flemming. *Automated Vehicles: The Coming of the Next Disruptive Technology*. Ottawa: The Conference Board of Canada, 2015.

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Acknowledgements

This report was authored by Paul Godsmark, Barrie Kirk, Vijay Gill, and Brian Flemming. The authors thank Peter Wallis of The Van Horne Institute for his views and guidance. The authors also thank Satyamoorthy Kabilan and Louis Thériault of The Conference Board of Canada for their opinions and comments; and Lina Kattan (University of Calgary) and Stephen Erwin (Ministry of Transportation Ontario) for their comments on an earlier draft of this report.

Funding and in-kind support for this briefing were provided by The Conference Board of Canada's Centre for Transportation and Infrastructure, The Van Horne Institute, and The Canadian Automated Vehicles Centre of Excellence (CAVCOE).

CAVCOE is dedicated to helping public and private sector stakeholders prepare for the arrival of automated vehicles.

The Van Horne Institute is recognized both within Canada and internationally as one of North America's leading research institutes focused on transportation, supply chain and logistics, and regulatory affairs issues.

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EXECUTIVE SUMMARY

Automated Vehicles: The Coming of the Next Disruptive Technology

At a Glance

- Automated vehicles (AVs) are, in some forms, already here. If history is a guide, their rollout may occur rapidly.
- AVs have the potential to bring many benefits, particularly in the form of saving us time and reducing the number of road collisions.
- Conversely, as AVs roll out, they will also be disruptive in the process.
- Governments and businesses must begin to plan for the arrival of AVs sooner, rather than later.

The arrival of automated vehicles (AVs)—also known as autonomous, self-driving, or driverless vehicles—is imminent. Canada is beginning to lag in recognizing and preparing for the large impact this disruptive digital technology will have on our society.

This report contains five key messages:

First, it examines the current status of AV developments and the rollout during this decade and the 2020s. The first generation of AVs is already with us. Google has already—as part of its “Chauffeur Project”—rolled out prototype AVs in California and elsewhere. But, there are numerous other developments in the U.K., Singapore, and other countries that are speeding up the development of AVs.

Second, the report addresses the economic and social impacts AVs may have and summarizes the benefits they will deliver to Canada. There is, of course, significant uncertainty regarding the extent and timing of an AV rollout—as well as its potential benefits. As a result, our approach to measuring these impacts is an illustration of the magnitude of potential that AVs can bring. For example, AVs could play a significant role in reducing current annual road fatalities by 1,600 from the current 2,000 a year. Further, we estimate that the total economic benefit may be over \$65 billion per year, including collision avoidance, fuel cost savings, and congestion avoidance. As with any significant technological change, there are winners and losers. The former typically outweigh the latter, but the potential wealth-transferring impacts are as important for governments to understand as the benefits. In this report, we speculate on some of the winners and losers in the economy.

Third, the report assesses the impact of AVs on transportation infrastructure. It contends that no major infrastructure project should be undertaken in Canada without an “AV impact audit” that governments

We see the widespread adoption of AVs as being a matter of “when,” not “if.”

and the private sector should be conducting. Naturally, what such an audit or assessment looks like is subject to debate and discussion as we just begin to understand what the potential impacts are.

Fourth, the report details the reduction in Canadian household transportation costs that will be delivered by AVs. Personal expenditures on transportation are one of the most significant expenditure items for Canadian households. We estimate that the total potential cost savings are nearly \$3,000 per household, or approximately \$2,700 after considering a 10 per cent rebound effect, in 2012 prices and activity levels. This represents close to 4 per cent of the total household budget, or over 5 per cent of total household consumption. The savings could be much higher if we take into account the potential impact that AVs have on reducing freight transportation costs—which make their way into the goods that we buy on a daily basis.

Fifth, the report calls on the newly appointed federal review of Canada’s transportation policies to study the arrival of AVs in Canada and support the scholarship that is necessary for Canada to keep pace with this rapidly evolving technology.

We see the widespread adoption of AVs as being a matter of “when,” not “if.” But there will certainly be a number of obstacles along the way. Potential obstacles include pushback from labour (as many jobs will be displaced); keeping regulations up-to-date with such a rapidly evolving technology; cyber security issues; and insurance and liability issues.

Governments and industry are often not prepared for the impacts of new technology due, in part, to the fact that the change is so rapid. In some cases, governments may even impede the adoption of new technologies due to antiquated regulations. The growing regulatory response to technologies such as ride-sharing applications (for instance, Uber and Lyft) is perhaps the best current example. And many businesses beyond those that provide the technology and build automobiles will be affected by the AV rollout. These include any businesses involved in freight or passenger transportation, car-sharing and car rental companies, insurance companies, and retail and commercial building management

companies (who often provide large numbers of parking spaces), just to name a few. Because of their widespread effects, AVs will require active planning on the part of all levels of government and businesses in Canada.

Five potential priorities for Canada are the following:

1. Augment political leadership at the federal level, comparable with what we see in other countries, especially for the impact on vehicle standards, the technology sector, the auto industry, and the economy. Provincial and local governments are largely responsible for the delivery and operation of road infrastructure, but the federal government can play a coordinating role in order to encourage harmonization rather than fragmentation.
2. Enhance political leadership at the provincial and territorial level for transportation systems and regulations. Transportation infrastructure investments are typically planned and implemented based on forecasts of travel demand of 30 years or longer. AVs will certainly be a reality well within that time frame.
3. Boost leadership at the municipal level to incorporate the impact of AVs into urban planning, transit, and the design of infrastructure projects—and for the same reasons as above.
4. Measure the potential impact of AVs on Canadian businesses. For many, AVs will provide an opportunity to reduce costs and do business more efficiently. Other businesses may be marginalized, unless they can adapt early enough to take advantage of the beneficial aspects of AVs.
5. Encourage the creation of a Canadian ecosystem to compete for a share of the global market for AV software, parts, and components—or at least ensure that we are not erecting barriers to this happening organically.

This report does not cover the entire gamut of the potential impacts of AVs. The potential impacts are so widespread that it can only scratch the surface. But it will hopefully stimulate the appetite to increase our understanding of what those potential impacts are, and how to prepare for them now, rather than later.

CHAPTER 1

Introduction

Chapter Summary

- It is a matter of “when,” not “if,” automated vehicles (AVs) will be on our roads. In fact, the first generation of AVs is already with us.
- AVs will affect our infrastructure needs and cause us to reorganize where we live and work. They will bring great potential benefits but, as with any transformative technology, will also bring great disruptions in the process of their rollout.
- Governments and the private sector would be wise to start planning and preparing for the arrival of AVs sooner, rather than later.

The world is about to experience the dramatic impact of many disruptive digital technologies, ones that will transform our 21st-century civilization beyond recognition. Among these are mobile phone technology, especially 5G, which will be commercially available about 2020; quantum computing; 3D printing; nanotechnology; metadata mining; and fission power. But the transformative technology that will soon impact the average person the most is the arrival of automated vehicles (AVs), also known as self-driving or driverless vehicles. AVs are not just on the drawing board, but are actually operating, or about to operate, in many parts of the world. Canada lags with respect to the policy, industrial, and legal implications of AVs.¹

This report is intended to be a wake-up call for public and private policy-makers, who must act soon to keep Canada in the “game” of automated vehicles. AVs will be nothing less than the first widely available “autonomous robots” to be used by nearly everyone in the world’s advanced economies.

The authors of *The Second Machine Age*² tell readers that the world is at an “inflection point” that heralds “the dawn of the second machine age.” The same source states: “The Industrial Revolution ushered in humanity’s first machine age—the first time our progress was driven

- 1 One exception is Ontario. The mandate letter from the Premier of Ontario to the Minister of Transportation includes establishing a regulatory framework for autonomous vehicles. The Ministry of Transportation (MTO) has started a second round of stakeholder consultations as part of this process. MTO, the Ontario Centres of Excellence, and the Ministry of Research and Innovation have teamed up and have announced a Connected Vehicle/Autonomous Vehicle (CVAV) Research Program.
- 2 Brynjolfsson and McAfee, *The Second Machine Age*.

primarily by technological innovation—and it was the most profound time of transformation our world has ever seen.” Today, “digital technologies—with hardware, software, and networks at their core—[can] accomplish many tasks once considered uniquely human.”

The first generation of AVs is already with us. Google has already—as part of its “Chauffeur Project”—rolled out prototype AVs in California and elsewhere. These included adding AV technology to standard cars and custom-designed, small, two-seater electric vehicles. The government of the United Kingdom is promoting the testing of AVs in Milton Keynes, Buckinghamshire. Singapore is to start testing AVs on its public highways in 2015. The European Union (EU) has matured its research into the current CityMobil2 program³ to help develop AVs and has modified its treaty law to allow the introduction of AVs in Europe. Mercedes-Benz is moving, incrementally, toward the development of AVs: it already has demonstration vehicles capable of 99 per cent autonomous operation and commercially available vehicles that are 70 per cent autonomous. And the Cadillac division at General Motors is promising a “super cruise” technology in its 2017 models. The Cadillac technology will not only allow control of the car to be handed to a computer, but will also feature a “vehicle-to-vehicle technology.” The technology will allow Cadillacs to communicate with other vehicles and to predict, and avoid, highway hazards. Nissan is working on a range of AVs that it claims will be for sale sometime between 2020 and 2025. Tesla has already stated its intent to have cars that can “... drive from highway on-ramp to highway off-ramp ...” in 2015. The State of Nevada has passed legislation to permit AVs on its highways. In Alberta, Suncor is operating an autonomous large dump truck in the oil sands. And Navya Technologies has launched the Navya, a fully autonomous electric shuttle for college campuses, airports, and other locations where there is a need for low-speed vehicles. (See Chapter 2, Exhibit 1.)

3 CityMobil2, *Assessing the Impact of Automated Road Transport Systems*.

We believe Canada must quickly find natural niches for itself in the fast-moving world of AVs. Is there any reason why Canada shouldn't develop the first road-legal autonomous snowplow?

As the list of companies and governments promoting or permitting AVs grows exponentially, Canadians must ask the question, Where is Canada positioned as the age of AVs arrives? Historically, Canada has frequently been behind as new technologies have been introduced. The manufacture of automobiles slipped from our grasp early, as did the introduction of radio and TV when those technologies were in their infancy. Indeed, leading-edge technology—like Nortel and the Avro Arrow—flew across the corporate skies of Canada but soon, for various reasons, disappeared.

There are some areas where Canada has excelled in technology. Canada launched and operated the world's first commercial, geosynchronous communications satellite. Today, Telesat Canada is still a well-respected, major player in global satellite communications. And, in 1956, Toronto installed the world's first computerized traffic signals.

The AV world offers Canada an opportunity to join world leaders in developing an AV ecosystem that includes hardware and software developers, universities, etc. Simply put, we believe Canada must quickly find natural niches for itself in the fast-moving world of AVs. Is there any reason why Canada shouldn't develop the first road-legal autonomous snowplow?

Within the Canadian AV ecosystem, one star is beginning to shine brightly—i.e., QNX, the supplier of much of the world's most robust and resilient vehicle software. QNX is now partnering with VisLab⁴ of the University of Parma to develop autonomous vehicle systems. However, much more participation in this rapidly emerging ecosystem is needed for Canada to become a recognized leader.

The federal government of Canada recently commissioned the latest Canada Transportation Act Review, which will be conducted under the distinguished chairmanship of the Honourable David Emerson and a panel of five experts in various aspects of transportation policy. Emerson is scheduled to report his findings in December 2015. Because of the

4 QNX News Releases, *QNX Technology Powers Mission-Critical Systems*.

It is clear that AVs will be deployed in an incremental fashion, although there are different visions of what “incremental” means in this context.

extraordinary impact AVs and related technologies will have on many parts of the world of transportation—e.g., buses, trucks, taxis, trains, highways, bridges, subways, LRTs, etc.—we urge him to take into account the rapid emergence of AVs in Canada. In particular, we urge Emerson to recommend that all transportation infrastructure projects that receive federal funding should submit to an “AV audit.” This is so that irreversible long-term investments at least consider the potential impact of AVs on their viability. Most infrastructure projects are planned for decades ahead and are very expensive.

At the same time, we need to point out that in Canada, the majority of funding for road infrastructure is provincial and municipal. Provincial ministries of transportation and major urban municipalities need to prepare plans showing how they will take advantage of connected and automated vehicles, and begin building these into their long- and medium-term planning models. All levels of government—federal, provincial/territorial, and municipal—need to start budgeting now to make this happen.

AV technologies will dramatically impact many of these projects, from road building to urban transit, so everyone involved in transportation must take these technologies into account before committing to new projects. From our quick review of the potential impacts of AVs on road freight, there is even the possibility of consequential impacts on heavy rail and short-haul flights.

It is clear that AVs will be deployed in an incremental fashion, although there are different visions of what “incremental” means in this context. What is also clear is that AVs will have an enormous and disruptive impact on virtually all aspects of our country, our cities, and our society. The general scope of these impacts is known and described here, but there are a lot of unknowns regarding the details.

The objective in developing this report is to start the process of scoping out some of these impacts. The report also focuses on the benefits—technological and economic—that AVs will deliver, especially to Canada. It outlines the current status of AVs and the trends and addresses the

implications inherent in AVs for transportation infrastructure, particularly in our cities. And, it outlines the potential reduction in household transportation costs that will be delivered to the average Canadian home. As always, there will be winners and losers as the new technology overwhelms society. This *Automated Vehicles* report will inform us on who the winners and losers might be and how their newfound status will be impacted and, if necessary, remediated.

Much more research and planning will have to be done if Canada is to keep pace with these extraordinary new, game-changing technologies. This report is therefore a call for this research and planning to be undertaken as soon as possible.

CHAPTER 2

Status of Automated Vehicles and Trends

Chapter Summary

- Semi-automated cars are already commercially available, while fully automated vehicles are currently being used for industrial applications.
- Several manufacturers have indicated that they expect to have fully automated vehicles available by 2020–25.
- The timing of an AV rollout is uncertain. But, if the history of the rollout of automobiles is an indication, the rate of adoption can occur much more quickly than we might expect. For example, automobile purchases in the United States increased from 4,000 in 1900 to over 350,000 a mere 12 years later.

Automated vehicles (AVs) will be here much sooner than most people expect and will lead to major changes to transportation, our cities, and society as a whole.

Most car manufacturers and some technology companies are actively developing and testing AVs. Some preliminary versions of AVs are already commercially available:

- Semi-autonomous cars, such as the Mercedes Benz S-class, are already commercially available; capabilities include lane-keeping, acceleration, and braking.
- Suncor is operating an autonomous large dump truck in the Alberta oil sands.
- Navya Technologies has launched the Navya, a fully automated shuttle vehicle for campuses, airports, and similar low-speed applications. (See Exhibit 1.)
- The City of Milton Keynes in the United Kingdom will receive its first driverless taxi “pod” in 2015. Testing will start in the pedestrian-friendly city centre later the same year. (See Exhibit 2.)

Rollout

The probable future rollout of AVs will be evolutionary, although Google and the car manufacturers have different visions.

Google is likely to start with an electric, fully automated, low-speed (40 kph), two-seater prototype vehicle. A pilot project on the private grounds of the NASA Ames Moffett Field facility has already been announced. An additional public pilot project using 100 to 200 of these vehicles is also anticipated to start in 2015 or 2016 in California. Regulations allowing the operation of fully autonomous vehicles come into effect in California on January 1, 2015. Google also aspires to have vehicles that are capable of travelling fully autonomously on city streets and freeways in the public’s hands by 2017–19.

Exhibit 1
The Navya



Source: Navya Technologies.

The car manufacturers are planning to deploy AVs using a different evolutionary approach. They are gradually adding “Advanced Driver Assistance Systems” (ADAS) to familiar vehicle models. This will start with high-end models and then work down to lower price point models. Current ADAS systems include lane-keeping, intelligent cruise control (including braking), and automated parking.

By 2020, most major car manufacturers intend to have vehicles in their showrooms that are capable of driving themselves for some of the time. By 2025, several manufacturers have indicated that they expect to have fully autonomous vehicles. It is worth noting that the automakers’ current business model favours retaining the driver in the loop to preserve private ownership.

Exhibit 2

Milton Keynes' Electric Automated Taxi



Source: Conceptual design courtesy of RDM Group.

The possibility of AV functionality being achieved by the installation of aftermarket systems should not be discounted. Even though current legislation being developed in California does not appear to allow for this eventuality, most or all jurisdictions may consider it an acceptable route to full automation, provided the liability issue is addressed. This could influence deployment and market penetration forecasts, especially if aftermarket kits can be manufactured and fitted more rapidly than AVs can be manufactured.

Many predict that the infiltration of AVs will be relatively small during the final years of this decade. The period 2020–30 will see more substantial growth in the population of AVs, but the estimates for this vary considerably. The speed of adoption of this new technology could be much more rapid than current studies have predicted based on prior

automotive technology deployment rates. This is because of the complex socio-economic factors and trends influencing demand and the new business models that AVs facilitate.

Rate of Adoption

The rate of adoption of AVs and the associated market dispersion will be based on several factors.

First, the rate at which technologies are being adopted by users¹ is accelerating—along with the rate that technology is being developed. For those who argue that the switch over to AVs from the existing human-driven fleet will take many decades,² it is worth noting that it took about a dozen years for New York to switch “from horse power to horsepower”³:

In 1900, 4,192 cars were sold in the U.S.; by 1912 that number had risen to 356,000.

In 1912, traffic counts in New York showed more cars than horses for the first time. The equine was not replaced all at once, but function by function. Freight haulage was the last bastion of horse-drawn transportation; the motorized truck finally supplanted the horse cart in the 1920s.

There is a compelling business case for AVs that, because they can do work by moving people and goods, they can make money for their owners. AVs will be the first “autonomous robots” that the masses can potentially own and put to work. Because of the money-making potential of AVs, it is not unreasonable to anticipate that there will be considerable pent-up demand and that they will initially sell faster than they can be made—similar to the experiences of Apple with their iPhone and iPad products. The expectation is that the majority of sales will be to fleet buyers rather than private individuals.

1 ASYMCO, *Adoption Rates of Consumer Technologies*.

2 Litman, *Autonomous Vehicle Implementation Predictions*.

3 Morris, “From Horse Power to Horsepower.”

By removing the driver from behind the wheel, AVs are expected to eliminate most of the 93 per cent of collisions that currently involve human error.

Another consideration is that the market infiltration of AVs will be leveraged by the transportation-as-a service (TaaS) principle, where we can expect a single, fleet-owned automated taxi to effectively replace numerous private vehicles. A study by Martin and Shaheen of UC Berkely⁴ found that a single car-share vehicle can replace between 9 and 13 private vehicles. Thus, the effective market penetration of AVs should not be confused with directly comparing each unit sold against each conventional car or vehicle sold, as most studies by analysts from the automotive sector have tended to do. Rather, the effective market penetration in a country would be a multiple of the actual saturation of AVs relative to the total number of all vehicles. Based on the most recent research, this replacement ratio of AVs to privately owned cars could be anywhere between 1:2 and 1:13—where any ratio of 1:1.2 or greater could itself be transformative in reducing congestion.

Benefits

AVs have many benefits: the most significant is safety. By removing the driver from behind the wheel, AVs are expected to eliminate most of the 93 per cent of collisions that currently involve human error.⁵ In a 2007 study commissioned by Transport Canada, road collisions had a societal cost of \$62 billion, or the equivalent of 4.9 per cent of GDP that year. By comparison, the U.S. societal cost estimate is \$871 billion⁶ (2010), or the equivalent of 6 per cent of GDP, and a direct cost estimate of \$277 billion, or 1.9 per cent of GDP. In 2011, there were 2,006 fatalities on Canada's roads.⁷ Therefore, if AVs can help to reduce this figure by 80 per cent⁸ by significantly reducing the impact of human error, then

4 Martin and Shaheen, "The Impact of Carsharing on Household Vehicle Ownership."

5 National Highway Traffic Safety Administration (NHTSA), U. S. Department of Transportation, *National Motor Vehicle Crash Causation Survey*.

6 National Highway Traffic Safety Administration, *New NHTSA Study Shows Motor Vehicle Crashes*.

7 Transport Canada, *Canadian Motor Vehicle Traffic Collision Statistics 2011*.

8 Even if AVs were able to eliminate all accidents currently caused by human error, there would inevitably be some collisions caused by machine error—meaning that the reduction would be something less than 93 per cent.

With AVs, the demand for parking will decrease substantially because an AV can relocate itself to an area of free parking.

AVs could save up to 1,600 lives a year. Road crashes are a leading cause of death in ten-to-34-year-olds in North America.⁹ As Dr. Louis Francescutti, an Edmonton emergency medicine physician, puts it “The greatest epidemic before us sure wasn’t H1N1, it was injuriesTraffic deaths are an unnecessary epidemic.”¹⁰

A second benefit of AVs is that they will stimulate a very strong trend toward a transportation-as-a-service model—i.e., the use of cars on a short-term rental basis as an alternative to ownership. This also naturally promotes ride-sharing as it is more cost effective and sustainable. This will develop into low-cost, automated taxis that can provide door-to-door service. We can expect that the existing taxi, car-rental, and car-share business models will converge. We also note the recent extremely rapid rise of Uber and its transportation service model, as well as the significant Google investment in Uber with both parties openly talking about how self-driving Uber vehicles are a very attractive proposition. Thus, with Uber, we can see how a credible path to automated taxis may already be mapped out for many cities.

A further benefit is the reduction in the need for parking spaces. Parking uses a huge amount of land in downtown areas. It is estimated that the U.S. has as many as eight parking spaces per car, and this may be the same in some Canadian cities. With AVs, the demand for parking will decrease substantially because an AV can relocate itself to an area of free parking. Or, as an automated taxi, it can pick up its next ride. In some cases, a commuter can send the car home for his/her spouse to use. In the TaaS model, the car simply drives itself to the next person who needs it. This has major implications for the reclamation of parking lots and structures for alternative uses that could benefit the community or be allocated for development. There is also a significant benefit when travelling by car to downtown locations in large cities. The current overall travel time includes the time required to find a parking spot, park the car, and then walk to the destination. There is also an uncertainty factor

9 Perez, “Guns and Car Crashes.”

10 Priest, “Pedestrian Fatalities an ‘Unnecessary Epidemic.’”

in estimating the time to do this. If an AV drops its passenger(s) directly at the destination, the overall travel time is reduced and the uncertainty about the time to find a parking space is eliminated.

There are strong synergies between the TaaS model and electric vehicles (EVs). This means that automated taxis will benefit from EV technology for most urban trips, and this will result in cleaner and greener cities. However, there will be a need for electric charging or battery swap stations. The increased demand for additional electricity generation and distribution infrastructure should be studied and planned for now.

Turning to transit, the introduction of AVs may lead to a lower-cost, personalized mass transit. TaaS means that users will be able to call a self-driving taxi, which will pick them up; take them to their office, home, or wherever they are going; drop them off at the front door; and then continue on to other customers. Existing proposals for traditional transit may not be as beneficial and cost effective as currently hoped, and a transit system based around AVs may prove to be the optimal solution. Given that transit projects currently in planning can take years, and sometimes more than a decade, to be constructed, and then have an expected operational life of many decades, AVs will be deployed well within the planned operational lifetime of transit. There is therefore a clear need for transit planning to take AVs into account.

Another benefit of AVs is that they will provide easily accessible transportation for many who are registered disabled (14 per cent of the population), are seniors (25 per cent of people over 65 don't have a licence), cannot afford to drive, or, for whatever reason, do not have a driving licence—including children. The freedom and liberty for these groups could be transformational.

Finally, the above trends will lead to greener municipalities for the reasons given above, as well as for other reasons. The reclamation of excessively paved areas, such as parking lots and garages, can lead to

more green/community spaces if policy steers decisions in that direction. The synergies between AVs and EVs will reduce air pollution levels in towns and cities.¹¹

Planning for AVs in Canada

Some preliminary work on planning for AVs in Canada has already started. On November 25, 2013, ITS Canada hosted an AV summit in Ottawa. Transport Canada was one of the organizations that attended and generously provided the conference facilities. The summit's objective was to take the first steps in getting Canada ready for AVs. The news release announcing the summit provides additional information.¹²

Ontario, as mentioned earlier, has a number of activities related to automated vehicles and connected vehicles (CVs).

The Canadian Council of Motor Transport Administrators (CCMTA) has a working group looking at the regulation of AVs. Transport Canada and the provincial and territorial transportation agencies are all members of CCMTA.

Also, Transport Canada is participating in international standards development activities related to AVs (UNECE WP.29, ISO TC 22 SC39, and ISO TC 204).

However, much more work is needed. The following chapters address three aspects of AVs in more detail. The aspects include the:

- impact of AVs on Canada's economy;
- impact of AVs on infrastructure;
- reduction in household transportation costs.

11 Although as explained later, the benefit of lower travel costs may result in more travel overall, thereby offsetting some of these potential environmental benefits.

12 ITS Canada, *ITS Canada Hosts Summit*.

CHAPTER 3

The Impact of AVs on Canada's Economy

Chapter Summary

- Canadians spend a lot of time driving—at least 5 billion hours per year. AVs have the potential to free up that time for productive or leisure activities.
- AVs could significantly reduce the number of vehicle collisions, as most are caused by human error. As these collisions come at a great cost, eliminating a large portion of them would bring great benefits.
- AVs also have the potential to reduce congestion on our roads, as well as reduce the amount of fuel that we consume.
- We estimate that the sum of these promising benefits could be more than \$65 billion per year. There are also further possible benefits that we discuss here, but do not attempt to quantify.

The potential scope for impacts of AVs on Canada is profound. No detailed research has been carried out to date on the socio-economic impacts of AVs. But a blue paper by Morgan Stanley estimated that, when AVs are fully deployed, the U.S. would save, in the base case, \$1.3 trillion per year (nearly 8 per cent of U.S. GDP in 2012) and, globally, the savings would be more than \$5.6 trillion per year.¹

The savings for the U.S. are estimated by Morgan Stanley as follows:

- Savings from collision avoidance will be \$488 billion—although we note that since the Morgan Stanley paper, the U.S. Department of Transportation has stated that the 2010 societal cost of road crashes was \$871 billion, or the equivalent of 6 per cent of GDP.² (The direct costs were \$277 billion, or 1.9 per cent of GDP.)
- Productivity gains from regained driver time will be \$507 billion—based on average commute times of 25.5 minutes for the U.S., which is similar to the Canadian average of 25.4 minutes.³
- Fuel savings will be \$158 billion—based on the improved efficiency of automated vehicles, reduced time spent driving around urban centres looking for parking spaces, etc.
- Productivity gains from congestion avoidance will be \$138 billion.
- Fuel savings from congestion avoidance will be \$11 billion.

What is clear from many studies is that the deployment of AVs will create many benefits. But this, in turn, leads to major employment displacement as well as other disruptions that are not identified in the Morgan Stanley paper.

1 Lewis, "Morgan Stanley Reports on the Economic Benefits of Driverless Cars."

2 National Highway Traffic Safety Administration, *New NHTSA Study Shows Motor Vehicle Crashes*.

3 Statistics Canada, *National Household Survey (NHS)*.

In Canada, there were 119,000 casualty collisions in 2011, resulting in just over 2,000 fatalities and over 160,000 injuries.

Next, we apply a similar methodology with available Canadian data, along with our own assumptions, to roughly estimate total economic benefits for Canada.

Collision Savings

The Morgan Stanley paper estimated total collision savings by assigning costs to each motor vehicle death and injury in the U.S. and then assuming that AVs would help to avoid 90 per cent of all motor vehicle collisions. In Canada, there were 119,000 casualty collisions in 2011, resulting in just over 2,000 fatalities and over 160,000 injuries.⁴

Any estimate of the total cost of collisions is highly dependent on the values assigned to fatalities in particular. A previous meta-analysis based on 37 studies that estimated the “value of a statistical life” (VSL) found a range of \$0.5 million to \$50 million (expressed in 2000 U.S. dollars).⁵ The Morgan Stanley report assumed a value of \$6 million. Meanwhile, previous research conducted for the Ontario Ministry of Transportation and Transport Canada assumed a range of \$7.5 million to \$19.7 million, with a mean value of \$13.6 million (expressed in 2004 Canadian dollars).⁶ Of note is the fact that higher estimates are typically based on a “willingness to pay” (WTP) methodology. This is where the value is inferred from observations of the extent to which individuals are willing to pay to avoid the risk of death or injury. Estimates based on other methods of evaluation, such as a discounted future earnings approach, typically result in significantly smaller VSLs.

If we assume the mean value of \$13.6 million inflated to 2011 values using the consumer price index (CPI) for Canada, we arrive at a mean VSL of \$15.6 million. This puts the cost of road fatalities in 2011 at over \$31.5 billion.⁷

4 Transport Canada, *Transportation in Canada, 2012*.

5 Bellavance, Dionne, and Lebeauc, “The Value of a Statistical Life,” 2.

6 Vodden and others, *Analysis and Estimation of the Social Cost of Motor Vehicle Collisions in Ontario*, 31.

7 $2,025 \text{ fatalities} \times \$15.57 \text{ million} = \31.54 billion .

Collisions that result in non-fatal injuries are far more numerous, but also less “costly” on average, than fatal collisions. Estimates of the cost per injury are also highly variable but are typically based on an estimate of activity and workdays lost due to injury. The lost days are multiplied by the value per activity or workday, health care, and emergency response costs per injury. Permanent and more severe injuries are thus assigned a higher cost than minor injuries.

The Morgan Stanley paper assumes an average cost per injury of US\$126,000, based on guidance from the Federal Highway Administration (FHWA). The previous research in Canada cited above estimated an average cost of \$82,000 (expressed in 2004 Canadian dollars). Inflating the latter value to 2011 dollars results in an average cost of \$93,900 (expressed in 2011 Canadian dollars). Applying this to the total number of non-fatal injuries in 2011 results in a total cost of \$15.2 billion.⁸

From the above, the total cost of road fatalities and injuries in Canada is estimated to be \$46.7 billion. In addition, we could calculate additional costs based on property damage and congestion delays. So, while the above estimate is highly sensitive to assumptions regarding the VSL in particular, it could be much higher if we were to include those costs, or if we were to factor in an expected higher level of total vehicle kilometres travelled (VKT) in the future. On the other hand, even without the rollout of AVs, we may expect that other vehicle safety improvements could help reduce collision rates to some extent in the future.

Based on those costs alone and the assumption that AVs could ultimately help to avoid a more conservative 80 per cent of the collisions that we witness today, the cost savings from collision avoidance are estimated to be approximately \$37.4 billion per year (expressed in 2011 Canadian dollars).⁹

8 $\$93,904 \times 162,168 \text{ fatalities} = \15.23 billion .

9 Note that we cannot consider this a “GDP impact” per se, as much of the value is driven by the WTP estimate, which is not counted in GDP itself. This does not make the value any less real. Rather, it should just not be portrayed as an addition to GDP.

A potential benefit of AVs is that they will allow individuals to focus on other activities while they are in their vehicles, which may result in increased productive time, increased leisure time, or a blend of both.

Time Value Benefits

Canadians spend a lot of time in their vehicles. A potential benefit of AVs is that they will allow individuals to focus on other activities (rather than driving) while they are in their vehicles. That may result in increased productive (working) time, increased leisure time, or more likely, a blend of both.

In 2009, total VKT by light-duty vehicles in Canada was over 303 billion.¹⁰ While the source survey of that estimate has since been discontinued, we can estimate growth in total VKT by inferring from other sources. For example, total gasoline sales increased by 4.3 per cent between 2009 and 2013.¹¹ Average fuel economy over the same period likely increased (although not to the degree that the average fuel economy of new vehicles increased because only a portion of the total vehicle fleet is turned over every year). If average fuel economy has increased by 0.5 per cent per year (or roughly 0.04 L/100 km), total VKT will have grown by approximately 6.4 per cent for a total of 323 billion.

To convert total VKT into an estimate of the total amount of time drivers spend behind the wheel, we require an estimate of average vehicle speed. In addition, a hypothetical average speed would have to be estimated based on the congestion-mitigating potential of AVs—the benefits of which are estimated separately. Since AVs have the potential to reduce congestion and decrease the time spent in vehicles, the benefits related to that time saved should not be counted twice.

A conservative measure then is to simply assume that vehicles would be travelling at free-flow or close to free-flow speeds. We assume this to be 90 kph on highways and 40 kph on local and arterial roads, with the simple average being 65 kph. Based on this speed, we estimate a total of 4.97 billion driver hours per year. Note that this includes only driver

10 Statistics Canada, *Canadian Vehicle Survey*.

11 Statistics Canada, CANSIM table 405-0002.

People will get to places with greater certainty and more directly since there is no need to find parking and to travel from parking to office.

hours, because it is assumed that passengers are already free to be productive or engage in leisure activities as they would if the vehicle was self-driven.

If they were free from the burden of driving the vehicle, how would drivers make use of these nearly 5 billion hours of time? It is unlikely that they would spend all or even most of their time working. One would expect that some of the time spent commuting to work would be spent working, and perhaps some of the time spent commuting from work as well. However, it is less likely that time spent in vehicles travelling for other reasons (shopping, visiting friends, etc.) would be put to so-called productive uses. Moreover, we would likely see at least some of the time spent working in vehicles cut into time spent in the workplace itself, meaning that the total number of hours spent working does not necessarily increase.

While not easily quantifiable, there are additional benefits related to the quality of life and work. First, there will be an increased efficiency of time. People will get to places with greater certainty and more directly since there is no need to find parking and to travel from parking to office. Second, people will arrive at their destination feeling more relaxed and less stressed. There may be productivity gains as well as leisure time gains for individuals resulting from this.

Given these factors, we are more comfortable in making the assumption that most of the time that is made available by AVs would be spent engaging in leisure activities. Additional leisure time does not directly contribute to GDP. However, leisure time is certainly valuable and, as a result, should be considered as a benefit.

Research that has attempted to estimate the value of travel time, and particularly the value of time for commute trips, has typically found the average to be approximately one-half of the wage rate.¹² However, the value of time is thought to vary considerably—not just by individual, but by time of day, trip purpose, road conditions, etc. In the current case, we

12 Small, *Valuation of Travel Time*, 9.

require an estimate of the average value of all travel time, not just time spent commuting. The opportunity cost of time spent with a vehicle full of family travelling toward a leisure destination, for example, is likely valued at something less than the time spent commuting to work. Furthermore, AVs would not necessarily unlock the full opportunity cost of that travel time, as the traveller is still captive to some extent and not free to engage in any activity that he or she might otherwise choose.

As a result, we would suggest that the value of time that would likely be unlocked by AVs is something less than the standard value of half the wage rate. While acknowledging that more research would be required to arrive at a better estimate of what this value would be, we somewhat arbitrarily chose one-quarter of the prevailing wage rate. The average hourly wage in Canada is approximately \$24,¹³ meaning that the value per hour that is unlocked would be \$6. Moreover, we assume that the roughly one-third¹⁴ of the time that drivers currently spend with passengers in the vehicle would not be used in a very different fashion if the vehicle were driving itself. Thus, we do not apply any additional benefit to that time. The estimated benefit based on these assumptions, then, is approximately \$20 billion.¹⁵

Fuel Savings

Potential fuel savings can result from the improved efficiency of AVs, reduced time spent looking for parking spaces, and fuel savings from driving in less-congested conditions. (The fuel savings were estimated separately in the Morgan Stanley paper—we avoid applying such an estimate here.) Annual net sales of gasoline in Canada amount to over

13 Based on 2013 data, estimated from CANSIM table 282-0069.

14 According to the Canadian Vehicle Survey from which we derived the estimate of 303 billion VKT in 2009, total passenger kilometres travelled were 493 billion in the same year. Assuming the average passenger load (when there were passengers in the vehicle) was 1.5, 95 billion of the total 303 billion VKT would have been spent with at least one other passenger in the vehicle.

15 $4.97 \text{ billion VKT} \times (2/3) \times \$6 = \$19.9 \text{ billion}$.

41 billion litres.¹⁶ Most of this is used for passenger transportation. We estimate this to be 85 per cent based on the share of motor gasoline attributed to passenger use from the Natural Resource Canada energy use tables.¹⁷ This leaves approximately 35 billion litres of fuel consumed each year by passenger vehicles, or about \$35 billion in fuel costs, net of excise taxes.¹⁸

For our estimate, we hold prices and activity levels constant, though both can be expected to grow over time. However, we must consider the fact that vehicles will eventually become more fuel efficient even absent the rollout of AVs. Depending on the rate of fleet turnover, meeting Corporate Average Fuel Economy (CAFE) standards in 2016 and beyond could increase average fuel economy by up to 35 per cent or more. This translates to over \$9 billion in annual fuel costs (again, based on today's activity levels and prices). Morgan Stanley estimates that an autonomous vehicle can be up to 30 per cent more efficient than an equivalent non-autonomous vehicle. We apply a much more conservative estimate of 10 per cent to the remaining fuel bill of \$26 billion, which results in further savings (attributed to AVs alone) of \$2.6 billion.¹⁹ This more conservative estimate would account for a greater number of “empty miles” as a result of AVs repositioning between the pickup and drop-off of different passengers. And, as well, a potentially significant rebound effect (although, as explained later, the rebound effect implies additional utility accruing to the user, and that benefit should be counted as well).

16 Statistics Canada, *CANSIM* table 405-0002.

17 NRCan, Comprehensive Energy Use Database.

18 For example, combined federal/provincial excise taxes in British Columbia are 30 cents/litre, in Ontario 24.7 cents/litre, and in Quebec 30.2 cents/litre. Based on a gross price per litre of between \$1.25 and \$1.30—notwithstanding the recent drop in fuel prices—the price net of excise taxes would be \$1/litre. Source: Petro-Canada, “Gasoline Taxes Across Canada,” <http://retail.petro-canada.ca/en/fuelsavings/2139.aspx>.

19 Later in this report, we estimate potential savings to households, including potential savings in fuel costs. Applying that fuel savings estimate across all households in Canada results in a total fuel savings estimate of approximately \$3 billion. The estimate is inclusive of fuel taxes.

One study found that annual congestion costs in the Greater Toronto and Hamilton Area alone were \$6 billion.

Savings From Congestion Avoidance

The congestion-mitigation potential of AVs is large given their potential to increase average vehicle occupancy through ride-sharing, reducing spacing between vehicles, and anticipating traffic patterns. However, the potential value of the savings is highly uncertain given the uncertainty regarding current congestion costs in Canada.

For example, one study estimated that total congestion costs in Canada's nine largest cities were between \$3.1 billion and \$4.6 billion in 2006.²⁰ The range was based on the congestion threshold, or the speed at which we start "counting" congestion. The higher end of the range assumed that highway congestion "started" when vehicle speed declined to 70 kph. The lower range assumed a value of 50 kph.

That estimate included the value of travel time, increased fuel consumption, and increased GHG emissions due to "recurrent" congestion. Non-recurrent congestion—or irregular congestion that occurs due to collisions—was not included. A previous study found that including non-recurrent congestion effectively doubled congestion costs.²¹ This would place the above estimate between \$6.2 billion and \$9.2 billion.

Other research conducted for specific urban areas in Canada found even higher values for congestion costs. For example, one study found that annual congestion costs in the Greater Toronto and Hamilton Area (GTHA) alone were \$6 billion (expressed in 2008 dollars).²² This implies that congestion costs across the country would be significantly higher than the previously cited estimate. The increase in the estimated cost is, in part, attributed to the fact that additional costs beyond time value, vehicle operating, and environmental costs were included. In particular, costs to businesses in the form of lost output were included as well.

20 Yanes and Zaverghi, *Cost of Road Congestion in Canada*, 7.

21 Transport Canada, *Costs of Non-Recurrent Congestion in Canada*.

22 HDR Corporate Decision Economics, *Metrolinx*.

More recently, another study estimated that congestion costs due to forgone agglomeration economies could add an additional \$5 billion to congestion costs in the same urban area.²³

Suffice it to say that if today's estimates of congestion costs are highly uncertain, even more so is the potential value of reducing congestion as a result of a rollout of AVs. Morgan Stanley optimistically estimates that AVs can wipe out most congestion in the United States. Moreover, Morgan Stanley's base estimate of congestion costs is high to begin with, as it starts "counting" congestion at anything lower than free-flow speeds. The potential congestion-mitigating effects and the associated value is an area that clearly needs more research for a better understanding of the underlying factors. But, if we were to take a relatively conservative estimate of current congestion costs in Canada to be approximately \$10 billion—and assume that AVs could wipe out half of that due mostly to eliminating most non-recurrent congestion alone—we arrive at a potential benefit of \$5 billion.

There are additional factors to consider when gauging the congestion impacts of AVs. They will lower the cost of travelling, as well as make "driving" more accessible to the share of the population that does not have a driving licence. Therefore, we would expect that AVs increase the total number of VKT and potentially offset some of the congestion reductions as a result. On the other hand, shared automated fleets have great potential to increase average vehicle occupancy through ride-sharing, with little inconvenience to users. This would further reduce congestion on our roads.

Total Potential Benefits for Canada

The cumulative potential benefits from the factors described above are \$65 billion per year (expressed in 2013 Canadian dollars), as summarized below:

- collision avoidance—\$37.4 billion

23 Dachis, *Cars, Congestion and Costs*.

- time value—\$20 billion
- fuel cost savings—\$2.6 billion
- congestion avoidance—\$5 billion
- total benefits—\$65,650 billion

It is worth reiterating that these benefits are highly sensitive to the various assumptions that have been applied. (See “Sensitivity of Benefits Relative to Key Assumptions.”) Ultimately, the benefits that are realized could be significantly higher or lower based on alternate assumptions. Furthermore, there are other factors through which AVs may impact the Canadian economy. Some of those factors are discussed next.

Sensitivity of Benefits Relative to Key Assumptions

Our estimate of the potential benefits of AVs is sensitive to several key assumptions:

The Collision Avoidance Potential of AVs

Most collisions are caused by human error. We assume that AVs will be able to eliminate most—but not all—collisions that are caused by human error. A more conservative assumption would reduce the total potential benefit.

The Value of a Statistical Life

Estimates of VSL are highly variable depending on the methodology chosen to arrive at such a value. Higher estimates of the VSL will yield greater potential benefits of collision avoidance. Methodologies that include only direct health care costs yield lower values than those that include forgone income over the remaining working life of the individual from the time of death. Other methodologies, which measure the VSL based on the willingness-to-pay to avoid the risk of death, may yield even higher values.

Any study that attempts to place a value on the potential benefits of reducing mortality rates is subject to this uncertainty. We use a VSL of \$15.6 million.

The Value of Time

The higher the value of time, the greater the potential benefits from time savings. Since a large portion of the potential benefits from AVs are in the form of time savings, the benefits are highly sensitive to the value that we place on that time. We use a conservative value of \$6/hour (one-quarter of the average wage rate).

Other assumptions—such as the base assumption for current congestion costs, the potential for AVs to reduce congestion, and the fuel economy benefits of AVs—affect our estimate of potential benefits, but to a lesser degree than the assumptions described above.

Finally, it should be noted that the estimate is based on the full deployment of AVs. Naturally, the benefits would be incrementally smaller in a scenario where AVs are only partially deployed.

Other Impacts on the Economy

Because of the magnitude of the impacts that AVs herald, it is important to also bear in mind the wider context of social, economic, and technological trends and changes that we might expect to influence and shape the near future.

There are a number of areas where major money flows are likely. First, substantial changes in land values are expected as it can be argued that AVs increase sprawl and urban intensification (densification) at the same time.

On the employment front, there are jobs and trades that will be directly affected by the deployment of AVs, and many times this number that will be indirectly affected. It is these “ripple effects” as direct impacts move to indirect impacts that will result in almost every Canadian and every Canadian business or organization being a stakeholder in this technology.

Direct employment displacement would include, but is not limited to:

- transport, truck, and courier service drivers (currently 560,000, or 1.5 per cent of the Canadian workforce)
- taxi drivers/chauffeurs (currently 50,000)
- bus drivers
- auto body repair
- auto insurance
- traffic police
- road safety professionals
- tow truck drivers
- driving instructors/trainers
- trauma surgeons
- critical care health staff
- medical staff involved in car crash victim rehabilitation
- health staff involved with organ and tissue donation
- parking attendants
- legal staff involved with auto collisions

Indirect employment impacts of AVs could affect many jobs or businesses that strongly relate to road transportation in some form. Research would be invaluable in identifying how many jobs would be affected, and to what degree, as some indirect job displacement appears to be inevitable.

On the positive side, there will be new business opportunities for the auto and technology industries, related to the design and manufacture of sensors, software, etc. for AVs. The size of this increase may partly depend on the extent to which the federal and provincial governments stimulate activity in the AV space as some countries are doing.

Given the synergy between AVs and EVs, the overall consumption of oil could decrease and will negatively affect Canada's oil sector. Conversely, the increased use of electricity will be positive for the natural gas, electricity generation, and distribution sectors because of the widespread use of natural gas for electricity generation. The impact on

The shared economy is about using fewer resources more efficiently, and Automated Vehicles might be the biggest contributor to this sector.

the oil industry will drive the GDP down and the impact on the natural gas and electricity sectors will drive it up. The net result on the GDP is to be determined.

Land values will be impacted. There is a strong likelihood that people will be willing to tolerate longer commutes if they are able to be productive in the vehicle, especially if it means that they can buy cheaper housing as result of the longer commute. This will result in sprawl, and a possible reduction in land values in existing suburban and ex-urban areas.

Paradoxically, densification can also be encouraged by AVs as there is less need for urban parking and more housing can be developed on existing parking lots and structures. This trend will be reinforced because the cost of transportation is reduced for city dwellers who use the shared automated vehicle fleets (the TaaS model) and do not own their own vehicle. The overall impact of land value changes on GDP, subsequent changes to land use, and impacts on associated businesses could have either a negative or positive impact on GDP.

The “sharing economy”—as currently being witnessed by the rise of companies like Airbnb and Uber—will also be an economic factor. It is clear that technology has facilitated the development of more efficient ways to utilize existing resources to the benefit of wider society. Although greatly resisted by incumbent business sectors such as hotels and taxi companies, the trend is one of continual challenge and change toward these new businesses and the resultant money flows will be significant. AVs will directly complement the argument by Uber, Lyft, etc. to deregulate the taxi industry to allow shared automated vehicle fleets to function efficiently and sustainably. The shared economy is about using fewer resources more efficiently, and AVs might be the biggest contributor to this sector. This could result in lower output for some industries, but not necessarily a net reduction in GDP because other industries may grow, as capital and labour are freed up for other uses.

The baby boomer bulge will result in an increasing percentage of the population who will demand AVs as a way of improving their quality of life and maintaining their independence for as long as possible. Similarly, millennials (Generation Y) are taking longer to obtain their

driving licences, own a vehicle, and reduce their average annual vehicle kilometres travelled. AVs allow the younger generations significantly improved access to transportation in a way that lets them maintain their increasingly connected worlds. These trends are likely to result in a net increase in GDP.

Although there will be significant employment displacement, there is a massive opportunity for all manner of new business models to emerge with AVs, which will create new employment. Just as the Internet has created business models and opportunities that most of us could never have dreamed of, the new AV ecosystem will be like a “physical Internet” that will generate untold opportunities. The potential magnitude of this net increase in GDP is impossible to gauge, but it could be very significant indeed.

Also, lifestyles will change. Within a few years of AV deployment, we will see major lifestyle changes for a small, but significant, proportion of the population that will result in major money flows. For instance, some workers from large companies to SMEs to sole proprietors will find that it is beneficial and cost effective to base their office in a vehicle to allow them greater flexibility to visit worksites and clients. They will be able to reduce overheads, particularly the cost of a fixed office (rent, property taxes, etc.) and increase efficiency. Aspects of these changes could either increase or decrease GDP.

Many cities are already discussing how they might take advantage of the new mobility that vehicle automation brings. Helsinki is hoping to make vehicle ownership pointless.²⁴ Singapore is becoming increasingly committed to exploring just how beneficial AVs will be in its very densely populated country²⁵. Not to be outdone, the mayor of Los Angeles, Eric Garcetti, has reiterated his desire for L.A. to be the first major city with a “driverless car neighbourhood.”²⁶ The quality-of-life benefits that AVs

24 Greenfield, “Helsinki’s Ambitious Plan.”

25 Channel NewsAsia, *Another Step to Making Driverless Vehicles on Singapore*.

26 CityLab, *L.A. Mayor Eric Garcetti*.

Overall, we estimate that 40 per cent of truck operational costs could be saved by automating the truck.

can bring to cities²⁷, with the right policies in place, are impossible to quantify. But there are clear benefits to the triple bottom line of social, economic, and environmental factors that would push up the various quality-of-life indices that are highly regarded and competed for around the world.

Road freight costs could be significantly reduced, while the efficiency of truck use could be greatly improved by removing driver working time restrictions. We anticipate a transition from the human driver 100 per cent of the time, to an “operator/driver” role where the truck takes on more and more of the driving task. This would likely be followed by a “chaperone” phase where one driver is initially responsible for a single truck before a single chaperone becomes responsible for multiple trucks in a convoy. After this, we anticipate that trucks will be driving unmanned. By far the biggest cost saving for trucking costs is the removal of the driver, as salary costs, expenses, health care, and insurances are removed or substantially reduced. Secondary cost reductions will result from improved fuel efficiency from the robot driver and reduced maintenance and repair requirements. This is because the truck will consistently drive as carefully as the very best human drivers do when they are at their highest level of performance. Overall, we estimate that 40 per cent of truck operational costs could be saved by automating the truck. In addition, it is possible that many truck operators will find that because the truck can work up to 20 hours a day, rather than being limited to 14 hours a day by a driver complying with working time regulations, an additional 43 per cent increase in vehicle efficiency can be achieved.

Social, Economic, and Technological Changes

Because of the wider context of social, economic, and technological change that will shape the world in the near future, it is important not to view AVs in isolation. Even if AVs are currently being seen as the

27 Godsmark, “Quality Streets.”

AVs might just be the first wave of autonomous robots that are made available for public use.

technology most likely to dominate surface transportation over the coming decades, the following are just a few of the issues that should also be considered.

All manner of technologies are developing exponentially and many may either converge or have a material impact on any predictions regarding AVs. The DARPA Grand Challenges that acted as a key catalyst to jump-start AV development in 2004, 2005, and 2007 have also accelerated robotic development, as witnessed by the 2012–14 DARPA Robotic Challenges (DRCs).²⁸ Similar exponential technology development and convergence could also occur in additive manufacturing (3D printing) that could fundamentally impact the ease with which AVs could be manufactured and therefore speed up deployment.

Vehicle automation could also be achieved by another route. In the 2013 DRC, one of the set challenges was for a robot to drive a conventional vehicle. The standard of the winning robot of this driving event was very poor by human standards, yet it still managed to complete the task. Just like the Grand Challenges, we can expect magnitude improvements in robotic performance with each subsequent year. It may therefore be reasonable to predict that this could result in autonomous robots being capable of entering a conventional car and driving it sometime around 2020–30. To add weight to this as a potentially credible outcome, the reader should note that Google, which is leading the development of AVs, has recently bought eight of the world's top robotic companies.²⁹ These very notably include Boston Dynamics, as well as SCHAFT, which won the first DRC. Google has also been buying many of the top artificial intelligence and deep learning companies. It has 5 to 50 per cent of the world's top machine-learning experts.³⁰ Therefore, AVs might just be the first wave of autonomous robots that are made available for public use, with all sorts of autonomous robots becoming commercially available within just a few more years.

28 Defense Advanced Research Projects Agency (DARPA), *DARPA Robotics Challenge*.

29 Sofge, "Why Is Google Building a Robot Army?"

30 Cadwalladr, "Are the Robots About to Rise?"

The advent of AVs and other autonomous robots can lead to even greater employment displacement, with more and more work being carried out by robots. The concept of “basic” or “guaranteed minimum” income and its implications could therefore be seen as a very relevant extension of any AV-related research around impacts on GDP.

Conclusions

AVs will provide major benefits, but also potential obstacles, to the Canadian economy. And, it is unclear what the overall impact will be. However, it is obvious that there are significant potential benefits for the Canadian economy. Savings would result in financial flows that would be available to boost other areas of the economy and could be used to mitigate some of the downsides to the GDP that should be identified in more detailed research.

What is clear is that AVs will bring socio-economic change on a scale that means it will not be business as usual for government, companies, or the public. And, there will be financial flows that could have a substantial impact on the Canadian GDP.

Finally, it is vital to remember that something as potentially transformational as AVs should not be considered in isolation. Any predictions around AVs require constant horizon scanning to determine the potential impacts that other technologies and “megatrends” might have on AV deployment and market penetration.

CHAPTER 4

The Impact of AVs on Infrastructure

Chapter Summary

- AV developers are focusing on making AVs that can exist with our current infrastructure, rather than relying on the development of new infrastructure to accommodate them.
- After they are introduced, AVs will force us to redefine our infrastructure needs and adapt our infrastructure investment to take full advantage of the AVs' capability.
- Major transportation infrastructure investments are typically planned with 30-year time horizons in mind. As AVs are certain to be part of our lives well within that time frame, it makes sense to begin anticipating their impacts on those investment needs now.
- AVs will also make shared fleets more attractive, as they can reposition themselves. This may have a large impact on the rate of individual car ownership.

The impact of AVs on infrastructure will be significant. The best proxy for this is to look back to the early years of the 20th century. When the first cars were introduced, sales volumes were large and the impact on infrastructure was huge. Roads, traffic management systems, parking, gas stations, etc. were built to accommodate the adoption of the new technology. We can safely predict that the change to AVs will lead to changes of a similar order of magnitude.

First, however, we need to state two fundamental characteristics concerning AVs and infrastructure:

1. Numerous AV developers—and Google in particular—are very keen to ensure that their AV technology can operate on existing roads and infrastructure without any modifications. The intention is to incorporate enough sensors, software, and intelligence into the vehicles so that they are not reliant on additional external infrastructure or communications. The main argument for this approach is that it will be prohibitively expensive to modify all existing infrastructure (highways, urban arterials, side streets, rural roads, intersections, etc.) and no government agency or combination of agencies will be able to afford it. This also means that AVs will be able to function without connected vehicle (CV) technology, which is a separate technology to improve road network operational safety and efficiency.

CV technology includes vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems, both of which are under development and rapidly approaching deployment. Although CV technology will not be necessary for the operation of AVs on a millisecond-by-millisecond basis, there are a range of applications where CV technology is either useful or essential to AVs. Examples of use include downloading the latest maps and downloading updated operating systems and driving software.

V2V communications to prevent collisions provide an extra layer of safety. All the sensors on AVs provide a huge volume of video and data on road and traffic conditions, which can be uploaded. CV technology can transmit road sign and traffic signal information to cars, resulting in significant cost savings. And if no human is driving, Internet usage for “infotainment” will increase.

2. Although infrastructure changes are not essential for their safe operation, AVs will lead to the desire to make major changes in infrastructure. This will be done to maximize the benefits that arise from the fundamental differences between human-driven and computer-driven vehicles. To continue the analogy, when the internal combustion engine took over from horse-powered carriages, there was no need for hitching posts or troughs of water, but there was demand for better roads. The new infrastructure changes we can expect in the AV era are the focus of this section.

The impact of AVs on infrastructure is addressed in two parts:

- standard transportation infrastructure, which is defined as the existing road network and associated structures that are encountered in everyday driving;
- proposed major infrastructure projects—which can include new roads, tunnels, bridges, interchanges, and parking structures, as well as major new residential or commercial developments reliant on road access. The new bridge over the St. Lawrence in Montréal is used as an example of this category.

Standard Transportation Infrastructure

Although, as mentioned above, AVs are being designed to travel on existing roads without requiring modifications to the infrastructure, there are numerous ways in which AVs will have an impact.

Road utilization will increase because AVs will be controlled by computers that will be far more situationally aware than human drivers and have much faster reaction times. This means that, where laws allow,

We can predict that some signage to assist human drivers could be phased out and replaced by local transmitters that send data directly to the vehicles.

AVs will be able to safely travel closer together, thereby increasing the capacity of existing roads as measured in vehicles per hour. When we incorporate the convergence of AVs and connected vehicles, the trend will accelerate because the headway between vehicles can be further reduced. The overall benefit is a reduction in the need to expand existing roads and highways and/or build new ones.

Some roads may also be subdivided into AV and non-AV lanes simply by restriping them. Alternatively, we can determine parallel routes as AV and non-AV vehicles—so that there are low-cost conversion options available to highway operators.

Modelling studies that have been conducted in the U.S. show that roundabouts are more efficient for AVs than traffic signals. This is because computers are better at managing the merging process between different lanes of traffic. As the population of AVs increases, there will likely be a gradual replacement of signalized intersections with roundabouts.

Similarly, we can predict that some signage to assist human drivers could be phased out and replaced by local transmitters that send data directly to the vehicles.

We also encourage agencies to commission several more modelling studies to better understand the best practices. For example, at which level of penetration into the fleet should we change the operation of the road (dedicated lanes, roundabouts, etc.) in order to take advantage of the AV? What are the new operating parameters for AV-based networks? How do we operate with different levels of a mixed fleet? At what point do we decide that specific areas of the province or community switch entirely to AV operation?

With TaaS, we can expect that there will be considerably more ride-sharing. This will significantly impact future traffic flows, traffic forecasts, and tolling revenue models. The growing trend for urban dwellers and millennials to not own vehicles and to use transit more will accelerate. Professor Kornhauser of Princeton University has synthesized approximately 32 million daily trips in New Jersey and has predicted

The need for large, expensive transit park-and-ride lots will decrease—people will be able to travel from home to a transit station via AV and then send the AV home.

that with ride-sharing based around 2-to-10-minute wait times, the average vehicle occupancy during peak flows can increase from around 1.3 people to 2.9.¹ With increased ride-sharing at peak periods, more people can be moved by fewer vehicles, with consequential impacts on congestion reduction.

Another impact on infrastructure was mentioned earlier: the need for fewer parking lots. The arrival of fully automated taxis that provide TaaS means that far fewer people will need to park their vehicles at their destination. Instead, the automated taxis will travel to the next customer. For people who own their own AVs, there is also the option to send the vehicle home where it will park itself until it is summoned for the next trip.

However, the parking lots that remain will need far more charging points. There is a clear synergy between AVs and EVs, especially for travel within a town or city—which is where most of us travel most of the time. The latest Google two-seater electric vehicle and the Milton Keynes' pods are both examples of this. People who choose to continue private ownership can park their AVs in parking lots and garages and will want to plug their vehicles into charging points.

One outcome from the installation of large numbers of charging points in cities is the impact on the electricity companies' power distribution infrastructure.

Similarly, the need for large, expensive transit park-and-ride lots will decrease. People will be able to travel from home to a transit station via AV and then send the AV home, possibly to enable other family members to go to work or school. This will significantly reduce the cost of the "last mile" portion of using public transit. It will also decrease the cost of building and maintaining park-and-ride lots.

It is important to note that in dense travel corridors, the need for existing mass transit will remain because AVs will have a limited impact on existing high-volume transit routes during peak periods. Traditional mass transit is a very efficient way to move a lot of people relatively quickly.

1 Zachariah and others, *Uncongested Mobility for All*, 12.

However, AVs can be useful in providing the “last mile,” i.e., from home to the transit station and from the destination transit station to the final destination. Outside of peak periods, there will be benefits in changing to an AV-based service that can provide a door-to-door service at a cost that is lower than or comparable with running little-used mass transit options. Also, AVs will impact the need for park-and-ride, as mentioned above, and will reduce the need for large buses for low-volume routes in suburban and rural areas, especially outside of peak periods.

Linked to transit is the key trend that is gaining significant policy support, known as transit-oriented development (TOD). TOD refers to a strategy by developers to build office, retail, and residential structures close to transit stations. With the trend to low-cost TaaS, the benefits of TOD will be reduced, and investments in such developments could be undermined by resultant changes in land values.

There will be an impact under environmental impact laws and regulations. Under the *Canadian Environmental Assessment Act 2012*² and the relevant provincial and territorial acts, there is a requirement that unnecessary environmental impact be avoided unless justified. Because of the transformational changes that AVs could have, it is becoming increasingly possible that an alternative solution or option to meet defined project needs could involve the promotion of an AV-based solution, as it would involve less environmental impact. Future infrastructure projects requiring environmental impact assessments could therefore face a legal challenge on environmental grounds if they haven’t considered AVs as part of the planning and design.

A final point related to infrastructure, and looking further ahead: there are quality-of-life and economic benefits to establishing AV-only zones in urban centres.³ This is an extension of the concept proposed by the mayor of Los Angeles. AV-only zones enable a municipality to accelerate the AV benefits mentioned earlier and provide an opportunity for a city

2 *The Canadian Environmental Assessment Act 2012.*

3 Godsmark, *Quality Streets.*

Some thinking on platooning indicates that the most efficient systems will be when automated pods are physically touching—as with trains on railways.

to brand itself as new and different, which should attract people and businesses to that jurisdiction. AV-only zones will be controversial at first, but so was the London (U.K.) Congestion Charge Zone (CCZ).

Proposed Major Infrastructure Projects

Planning for AVs will be especially important for major infrastructure projects. The planned new bridge over the St. Lawrence in Montréal is taken as a case study.⁴ AVs will have the following impacts on the new bridge for the St. Lawrence corridor.

First, as mentioned above, it is generally accepted that AVs can travel closer together because the sensors and software can react to problems faster than human drivers. Some thinking on platooning indicates that the most efficient systems will be when automated pods are physically touching—as with trains on railways. This could create many issues in policy and enforcement for a tolling system.

Second, fully automated AVs include the “body out” case—i.e., cars and trucks that have no one in them. There will also be frequent cases where the occupants are children, disabled people, or inebriated people who have “passed out”. The tolling system needs to accommodate these scenarios.

Third, enforcement on the bridge will also change. How will police pull over a vehicle with no one in it, and when they do, what is the procedure for dealing with the vehicle? Similarly, if there are children in the vehicle but no adults, simply towing the vehicle is clearly not an option. These are issues that need to be addressed and that could impact the design of shoulders and/or the adjacent roadway approaches.

In the U.S., there is interest in AV-only lanes for cars and/or trucks. Consideration should be given to whether the new bridge might need to accommodate such lanes in the future and what form they might take.

⁴ The new bridge will be in service in 2018; the rest of the corridor will be completed in 2020.

Automated vehicles can travel more precisely and closely across the width of the lanes and overall roadway, as well as more closely to edge barriers and containment structures.

The trend toward transportation-as-a-service, as described above, could include one-seater versions that will be able to use lanes that are significantly narrower than current standards. Or, the vehicles could lane-split or lane-share in the same way that motorbikes do. The shorter length of these types of AVs will also change lane utilization forecasts. The tolling system will need to be flexible enough to cope with these lane-use scenarios.

As a result of TaaS and ride-sharing, it is predicted that the number of vehicles on the roads will decrease although the vehicle kilometres travelled (VKT) will likely increase. This alone might be revenue neutral for tolling considerations, but suggests a change in vehicle ownership and use that needs to be researched and better understood.

Future-proofing the bridge deck design, prior to construction, should be considered in order to maximize the capacity and expected service life of the bridge in light of AVs. Automated vehicles can travel more precisely and closely across the width of the lanes and overall roadway, as well as travel more closely to edge barriers and containment structures. Therefore, careful consideration should be given to the geometric needs of mixed-use lanes now compared with AV-only lanes in the future. It is almost certain that one additional lane could be accommodated within the existing conventional deck design, possibly by 2030. But careful planning could also possibly provide two additional lanes—if the bridge structure has been designed to accommodate these loads.

As a result of the automation of service vehicles, we anticipate that automated snowplows could be in operation in the same time frame. Therefore, reduced shoulder widths below current industry standards could be technically feasible without compromising operational safety. Automated snowplows can be stationed very close to the point of need and can be deployed more frequently than human-driven plows, at any time of day or night, at a reduced cost.

Finally, if the new bridge is to be procured by the public-private partnership (P3) route, the potential opportunities and risks represented by AVs need to be incorporated into discussions at the earliest

opportunity. P3 investors tend to be risk averse and the potential impacts of AVs will likely see them looking to transfer risk away from themselves and onto other parties in the contract—with inevitable project cost implications.

Conclusion

When designing infrastructure projects, there is a tendency to assume that the future is simply an extension of the past. AVs are a truly disruptive technology and we cannot forecast the future by simply extrapolating from the past. All of the above issues will change the forecasts for standard infrastructure and major infrastructure projects, tolling systems, revenue, etc.

Because major infrastructure projects that are being designed and built now will last for 30 to 50 years or more, i.e., well into the AV era, we recommend that all transportation-related infrastructure projects, especially major ones, include a detailed AV impact assessment study.

Project clients and sponsors will rightly point out that AVs are an unproven technology, and that no regulations, standards, codes of practice, or guidelines currently exist to assist with how to plan for this technology. It is therefore key that all parties involved in the concept, planning, and design process are educated about AVs and their potential impacts and that work is started as soon as possible to develop the necessary guidance documents.

CHAPTER 5

The Automated Vehicle's Impact on Our Wallets

Chapter Summary

- Canadian households spend more on transportation than they do on food, recreation, or clothing. AVs have the potential to change that.
- We conservatively estimate that AVs can save the average Canadian household nearly \$3,000 per year.
- This does not include the potential that AVs have to reduce freight transportation costs. These costs work their way into the goods that we buy, so reductions in freight transportation costs would likely result in further savings for households.

So far we have primarily discussed the potential impact of AVs at a macroeconomic level. Here we consider what the potential impacts are at the household level.

AVs have great potential to reduce household expenditures on transportation. This is significant, as Canadian households spend more on transportation than they do on most other goods and services. In fact, on average, Canadian households spend more on transportation (over \$11,000 per year) than they do on food (\$7,700), recreation (\$3,800), or clothing (\$3,500). Of consumption items (not including income taxes and retirement savings, for example) only expenditures on shelter (\$15,800) exceed expenditures on transportation. (See Table 1.)

Table 1
Expenditures Per Canadian Household, 2012
(current \$)

Total expenditures	75,443
Total current consumption	56,279
Shelter	15,811
Transportation	11,216
Food expenditures	7,739
Household operations	4,111
Recreation	3,773
Clothing and accessories	3,461
Health care	2,285
Household furnishings and equipment	2,183
Miscellaneous expenditures	1,430
Education	1,386
Tobacco products and alcoholic beverages	1,274
Personal care	1,194
Reading materials and other printed matter	214
Games of chance	202

(continued ...)

Table 1 (cont'd)

Expenditures Per Canadian Household, 2012

(current \$)

Income taxes	13,060
Personal insurance payments and pension contributions	4,272
Gifts of money, support payments, and charitable contributions	1,831

Source: Statistics Canada, Survey of Household Expenditures.

Of current consumption items, expenditures on transportation represent approximately 20 per cent. And this only includes spending on personal transportation. The impact of freight transportation costs—such as costs incurred for delivering materials to construction sites or delivering finished goods to retail outlets—is hidden in other categories. As a result, even relatively small changes in transportation costs can have a significant impact on household finances.

Of transportation expenses, expenditures on private transportation—primarily spending on purchasing and operating a personal vehicle—dominate. The average Canadian household spends about \$10,000 (or about 90 per cent of total transportation expenditures) on the purchase and operation of personal automobiles. (See Table 2.)

Technically it would be more consistent to include vehicle depreciation and financing costs in place of vehicle purchases (which are capital expenditures rather than current expenditures). Average depreciation and financing costs combined would likely be slightly higher than expenditures on vehicle purchases because they would include the entire universe of vehicles (not only vehicles that were purchased in the year of observation). They would also include a financing component, which is absent in cases where vehicles were purchased outright.

Table 2
Average Transportation Expenditures Per Canadian Household, 2012

(current \$)

Transportation	11,216
Private transportation	10,087
Private-use automobiles, vans, and trucks	4,256
Purchase of automobiles, vans, and trucks	3,875
Accessories for automobiles, vans, and trucks	50
Fees for leased automobiles, vans, and trucks	331
Rented automobiles, vans, and trucks	52
Automobile, van, and truck operations	5,779
Registration fees for automobiles, vans, and trucks	375
Private and public vehicle insurance premiums	1,338
Tires, batteries, and other parts and supplies	378
Maintenance and repair of vehicles	968
Vehicle security and communication services	12
Gas and other fuels (all vehicles and tools)	2,394
Parking, and traffic and parking tickets	176
Other automobile, van, and truck operation services	45
Drivers' licences and tests, and driving lessons	93
Public transportation	1,128

Source: Statistics Canada, Survey of Household Expenditures.

As previously discussed, AVs have the potential to increase car-sharing and, in particular, reduce vehicle purchase costs. On the other hand, there is expected to be some incremental cost per AV, although this cost

is expected to decrease over time. As well, we would expect the fleet to be renewed more quickly due to the increased use per vehicle (at least those that are used as TaaS vehicles).¹

As referenced earlier, under the TaaS principle, a single car-share vehicle could replace between 9 and 13 private vehicles in areas where car-sharing is most likely to succeed. Other estimates suggest that the ratio may be in the range of 3 to 5 private vehicles to every shared AV, depending on the extent to which individuals would be prepared to ride-share as well.²

Here we assume a ratio of 5 to 1, but for only half of the population. In other words, we assume that where AV car-sharing works, each AV will be able to replace five private vehicles. The other half of the population continues to own and operate their vehicles privately (making the overall ratio 2.5 to 1). Under this scenario, household expenditures on vehicle purchases would decrease by over \$2,500 (in 2012 prices). These savings would be reduced by the incremental costs associated with AVs as well as increased fleet turnover. Assuming that AVs add approximately 10 per cent to the purchase price and that TaaS vehicles are turned over twice as often (half of the asset life of a typical vehicle) reduces these savings to \$1,600 per household.³

This assumes that household expenditures on vehicle operations remain constant—meaning that expenditures *per TaaS vehicle* increase five-fold. If we instead assume that vehicle operating costs per vehicle do not increase proportionately to usage, we would expect to see some savings in vehicle operating costs per household. For example, for a single TaaS vehicle that replaced five privately owned vehicles, we would expect

- 1 While the capital costs of TaaS vehicles will naturally be paid for by the fleet owner, we would expect those costs to flow through to users (in the per kilometre or per trip charge). Here we estimate the reduction in capital costs on a per household basis, even though those capital costs will technically become operating costs for TaaS customers.
- 2 Raddi and Claudel, *The Driverless City*.
- 3 While there is an expected incremental cost as a result of the implementation of the technology, there may be offsetting cost factors, such as the use of cheaper and lighter weight materials. As much of existing vehicles' weight is there to protect us from crashes, some of that weight would be redundant due to the improved safety performance of AVs.

to see higher insurance premiums per vehicle. However, rather than a five-fold increase in insurance premiums per vehicle (meaning that the premium for a vehicle that was previously \$1,000 increases to \$9,000), we might expect a smaller increase relative to the number of users (due to the expected decrease in collisions, for example). In a scenario where non-fuel vehicle operating costs increase at half the rate of the number of users (in the insurance example above, the premium per vehicle increases from \$1,000 to \$4,500), households would save a further \$1,150 in 2012 prices.

We would also expect an additional decrease in fuel costs, which at \$2,400 per household are currently the most significant vehicle operating cost. Assuming no change from 2012 prices (and no rebound effect), we would expect approximately 35 per cent savings from (regular) vehicles meeting 2016 Corporate Average Fuel Economy standards. If we assume incremental savings of 10 per cent from AVs, this would provide an additional \$240 in savings based on 2012 prices.

Finally, the expected rebound effect would offset all of the cost savings above to some degree. However, it is instructive to show the cost savings both before and after an assumed rebound effect. The reason is that the savings, after the rebound effect is included, do not consider the fact that users are likely generating increased utility as a result of the elevated vehicle kilometres travelled. In other words, the cost savings, prior to the rebound effect being included, show the potential cost savings that are available. Households then are expected to “trade in” some of these cost savings in exchange for increased utility that is presumably more valuable than the cost savings that they forgo.⁴

Table 3 summarizes the potential cost savings per household described above, both before and after an assumed rebound effect of 10 per cent.

4 At least some of the increased VKT would be due to the repositioning of AVs in order to respond to demand, in which case there is no corresponding increase in benefits.

Table 3**Summary of Potential Cost Savings of AVs Per Household**

(2012 \$ prices)

Capital cost savings	2,554
Capital cost savings including AV premium and turnover assumption	1,596
Non-fuel operating cost savings	1,152
Fuel cost savings	239
Total savings before rebound effect	2,988
Savings after rebound effect	2,716

Source: The Conference Board of Canada.

In total, the estimated cost savings are nearly \$3,000 per household, or approximately \$2,700 after considering a 10 per cent rebound effect, in 2012 prices and activity levels. This represents close to 4 per cent of the total household budget, or over 5 per cent of total household consumption.

As noted, the above analysis does not include potential savings in freight costs, some of which would be expected to flow through to households in the form of lower prices for consumer goods. Potential savings could be even greater if we account for the fact that AVs could move toward the use of ultra-lightweight (and cheaper) materials due to their improved safety performance. In Chapter 3, we estimated the value of the potential safety benefits of AVs, part of which are the result of lower health care costs. If we were especially optimistic, we might be inclined to assume that some of these savings would be passed on to households through lower taxes. Since we are not that optimistic, we do not assume any savings for households in this regard.

The estimates are also highly uncertain and depend heavily on the other assumptions that were noted. Lastly, there is no adjustment for the increased or decreased utility associated with time savings (due to less time spent parking or time spent in congestion), time losses (waiting for TaaS vehicles), or increase in productive or leisure time spent in the vehicle. The extent to which cost savings would be passed

on to consumers rather than be captured by businesses providing the technology required to enable AVs and operate shared fleets will as always be affected by the level of competition that is present.

In any event, it is very certain that household expenditures on personal transportation today are a major part of household budgets. As a result, even relatively small changes in vehicle costs and usage can have big impacts on those budgets.

CHAPTER 6

Conclusion

Chapter Summary

- AVs have the potential to generate major benefits for Canada. But they will also be disruptive in the process.
- In terms of disruptions, the most obvious is the potential disruption for the more than 500,000 Canadians who currently earn their living driving a vehicle.
- Given the rapid progress of the technology, keeping regulations up to date, cyber security, and insurance and liability issues will pose challenges for governments and businesses. Both must start to prepare now to meet these challenges.

AVs will be the first widely available automated robots for people living in Canada and in the advanced economies around the world. The impact of AVs will be immense and will affect virtually all of us. Although the general nature of these impacts is known, the precise details—such as a quantitative forecast of the rollout and the impact on traffic patterns—are to be determined. For example, as AVs make travel more accessible, we would expect that the demand for travel would increase, not decrease. And we are unsure by how much. By eliminating the need for a large inventory of parking spots that we have in our dense urban areas, AVs create the potential for more dense urban environments. But by reducing the costs of urban travel, they also create the potential for greater sprawl. The net impact is also to be determined.

Governments at all levels must quickly start to plan for the arrival of AVs, especially with large-scale infrastructure projects. They must begin to understand how profoundly AVs will impact their cities and Canadian society. New laws and/or regulations will have to be passed—as they already have been in California, Nevada, and other jurisdictions and are being developed in Ontario. These will allow AVs to be tested and used, and will set out the ground rules for their operation.

Governments in Canada need to start thinking about the benefits of AVs and how best to take advantage of them: the huge positive impact on the economy, the saving of lives, and the opportunities for Canadian industry to participate in the global AV ecosystem.

Many businesses beyond those that provide the technology and build automobiles will be affected by the AV rollout, including any business involved in freight or passenger transportation or retail and commercial building management.

Governments will have to play a major role, not only in permitting (and lightly?) regulating AVs, but also in helping to improve the crueler impacts of AVs on people such as truck drivers and taxi drivers. Currently, there are about 560,000 truck and courier drivers in Canada. Will they go the way of 1950s elevator and telephone operators? Possibly. They will need to be retrained with the help of government. What about taxi drivers, bus drivers, and railway train operators?

Many of the new AVs will be powered by electricity. Which new capacity, if any, will be needed to meet the new demand for power? And what will be the environmental impact of building this electrical capacity? Or will power largely come from solar (as Tesla is doing with its charging stations) or natural gas so that the environmental impact will be as small as possible?

It is obvious that the private sector is currently driving the research and development of AVs. But many businesses beyond those that provide the technology and build automobiles will be affected by the AV rollout. This includes any business involved in freight or passenger transportation, car-sharing and car rental companies, insurance companies, and retail and commercial building management companies (who often provide large numbers of parking spaces), just to name a few.

It is vital to remember that something as potentially transformational as AVs should not be considered in isolation. Any predictions around AVs require constant horizon-scanning to determine the potential impacts that other technologies and megatrends might have on AV deployment and market penetration.

There will certainly be a number of obstacles during the transition phase. The initial reaction of seeing a driverless vehicle on the road for the first time will be jarring for many. Their responses will influence the speed and nature of the transition. Other potential obstacles include pushback from labour (as many jobs will be displaced); keeping regulations up to date with such a rapidly evolving technology; cyber security issues

and privacy concerns; reliability of the technology during our harsh winters; and insurance and liability issues. How these challenges will be addressed will have an impact on the timing of an AV rollout.

As stated earlier, this report is a clarion call for Canadians to begin to appreciate what is about to happen to them. But, it is also a call for Canada's governments and the private sector to do the research and planning that will be necessary for this country to keep up with AV developments around the world.

Five potential priorities for Canada are the following:

1. Augment political leadership at the federal level, comparable with what we see in other countries, especially for the impact on vehicle standards, the technology sector, the auto industry, and the economy. Provincial and local governments are largely responsible for the delivery and operation of road infrastructure, but the federal government can play a coordinating role in order to encourage harmonization rather than fragmentation.
2. Enhance political leadership at the provincial and territorial level for transportation systems and regulations. Transportation infrastructure investments are typically planned and implemented based on forecasts of travel demand of 30 years or longer. AVs will certainly be a reality well within that time frame.
3. Boost leadership at the municipal level to incorporate the impact of AVs into urban planning, transit, and the design of infrastructure projects—and for the same reasons as above.
4. Measure the potential impact of AVs on Canadians businesses. For many, AVs will provide an opportunity to reduce costs and do business more efficiently. Other businesses may be marginalized, unless they can adapt early enough to take advantage of the beneficial aspects of AVs.
5. Encourage the creation of a Canadian ecosystem to compete for a share of the global market for AV software, parts, and components—or at least ensure that we are not erecting barriers to this happening organically.

Time is short. We must start now!

APPENDIX A

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PUBLICATION: 6744
PRICE: Complementary