

Connected and Autonomous Vehicles: Implications for Policy and Practice in City and Transportation Planning

by

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Foreword

My Area of Concentration for my Plan of Study is sustainable transportation planning for growth management. Connected and Autonomous Vehicles will change the urban landscape, the roles of governments and present new challenges to planners. This paper has allowed me to view transportation planning through the lens of emerging technologies and how this affects cities in the short and long term.

There are many sustainability and growth management implications with Connected and Autonomous Vehicles. For example, automated vehicles can foster decentralization because it easily enables travel however, if utilized correctly, automated vehicles can also compliment local transit systems to support intensification. This is especially important in Ontario (Canada's first province to allow testing of autonomous vehicles on public roads) as it directly relates to the goals and policies related to sprawl and sustainability as outlined in Ontario's four provincial land use plans: The Growth Plan for the Greater Golden Horseshoe (GGH), The Greenbelt Plan, The Oak Ridges Moraine Conservation Plan and the Niagara Escarpment Plan.

My Plan of Study views transportation planning for sustainability and growth management as a system of interconnected components that are environmental studies, social studies and economics. These components have been explored in this paper in relation to Connected and Autonomous Vehicles. The economic impact of transportation technologies throughout history, as well as people's travel patterns and behavior are discussed. Although Connected and Autonomous Vehicles are still new and its impact is fairly unknown, my research and exploration revealed economic, social and political trends that coincide with what my Plan of Study seeks to fulfill.

Lastly, this paper has allowed me to weave practice and academia together into a single project. Although nothing was exactly proven in this paper, this paper links academia with practice to engage in discussions pertaining to the impact of Connected and Autonomous Vehicles on cities, society and governments, in terms of possible outcomes and suggestions.

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List of Abbreviations

ACC	Adaptive Cruise Control
AHOP	Assisted Home Ownership Program
AI	Artificial Intelligence
ALV	Autonomous Land Vehicle
ATG	Advanced Technologies Group
AV	Autonomous Vehicle
AVIC	Autonomous Vehicle Innovation Centre
AVIN	Autonomous Vehicle Innovation Network
BRT	Bus Rapid Transit
CAV	Connected and Autonomous Vehicle
CBA	Canadian Bar Association
CMA	Census Metropolitan Area
CMHC	Canada Mortgage and Housing Corporation
CSD	Canadian Survey on Disability
CV	Connected Vehicle
CVAV	Connected Vehicle/Automated Vehicle [program]
DARPA	Defense Advanced Research Projects Agency
DGC	DARPA Grand Challenge
DSRC	Dedicated Short-Range Communication
ECAV	Electric Connected and Autonomous Vehicle
EHG	Erwin Hymer Group
FMLM	First Mile and Last Mile
ICT	Internet Communication Technologies
IEEE	Institute of Electrical and Electronic Engineers
IFAC	International Federation of Automatic Control
GGH	Greater Golden Horseshoe
GPS	Global Positioning System
HOV	High Occupancy Vehicle [lane]
HRT	Helsinki Transport Authority
IOT	Internet of Things
ITS	Intelligent Transportation Systems
LIDAR	Light Detection and Ranging
LRT	Light Rail Transit
MaaS	Mobility as a Service (same as “TaaS”)
MACAVO	Municipal Alliance for Connected and Autonomous Vehicles in Ontario
MANET	Mobile ad-hoc- Network
MCDM	Multi-Criteria Decision Making [approach]
MTO	Ministry of Transportation Ontario
NHTSA	[US] National Highway Traffic Safety Administration
OBU	On-Board Unit
OCE	Ontario Centres of Excellence
OGRA	Ontario Good Roads Association
OP	Official Plan

PIPE-DA	Personal Information Protection and Electronic Documents Act
PROMETHEUS	PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety
R2V	Roadside-to-Vehicle [communication] (same as “V2I”)
RSU	Roadside Unit
RV	Recreational Vehicle
SCI	Strategic Computing Initiative
SAE	Society of Automotive Engineers
SPIE	Society of Photographic Instrumental Engineers
TaaS	Transportation as a Service
TFP	Total Factor Productivity
TDM	Transportation Demand Management
TMP	Transportation Master Plan
TOD	Transit Oriented Development
UniBwM	Bundeswehr University of Munich
UofT	University of Toronto
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure [communication] (same as “R2V”)
V2V	Vehicle-to-Vehicle [communication]
V2V2I	Vehicle to Vehicle to Infrastructure[communication]
VaMoRs	Versuchstahrzeug fur autonome Mobilitat und Rechnersehen
VaMP	Versuchsfahrzeug für autonome Mobilität und Rechnersehen
VANET	Vehicular ad-hoc Network
VIAC	VisLab Intercontinental Autonomous Challenge
WatCAR	Waterloo Centre for Automotive Research
WAVE	Wireless Access in Vehicular Environments
WiMAX	Wireless Interoperability for Microwave Access
WLAN	Wireless Local Area Networks

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Abstract

Vehicular transportation is undergoing a technological change. Cars are being automated, which have significant implications for governments. Autonomous Vehicles (AVs) and Connected and Autonomous Vehicles (CAVs) can have significant benefits such as improved overall roadside safety and efficiency however, there may also be negative effects as well such as increased sprawl and social inequity. In Ontario, AV testing on public roads has been conducted under *O. Reg. 306/15*, which has also helped to establish Ontario as a leader of innovation in Canada. Before CAVs can be mass deployed in Ontario and Canada at large however, a number of barriers will need to be addressed such as legislation, infrastructure and cooperation between municipalities, and between municipalities and the automotive industry. Recommendations for municipal and provincial governments are provided.

1. Introduction

Transportation as we know it today is in the process of changing as a direct result of improvements to technology. We are witnessing an era of automobile automation, and much like how the motor vehicle shaped cities and societies when it was introduced in the early 20th century in North America, autonomous vehicles (AVs) are on the verge of breaching reality and will have economic, social and political implications as well.

Automation have been made possible due to advancements in computing and sensing technology, such as microprocessors, lasers, radar and cameras that work together in synchronization to make driving decisions without human input. The Society of Automotive Engineers (commonly referred to as, “SAE”) released Standard J3016_201609 that provides taxonomy for AVs based on their level of automation.

Level 0	<u>No Automation</u> : The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.
Level 1	<u>Driver Assistance</u> : The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
Level 2	<u>Partial Automation</u> : The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
Level 3	<u>Conditional Automation</u> : The driving mode-specific performance by an Automated Driving System of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.
Level 4	<u>High Automation</u> : The driving mode-specific performance by an Automated Driving System of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.
Level 5	<u>Full Automation</u> : The full-time performance by an Automated Driving System of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

Table 1 – SAE’s Standard J3016_201609 and levels of automation.

Adopted directly from SAE International (SAE International 2016a).

1.1 Objective of the Paper

The objective of this paper is to establish an understanding of what CAVs are, how CAVs will impact transportation and cities, the impact CAVs will have on governments, and what to expect from CAVs in the future. AV technologies are advancing at a rapid pace, so how can municipalities in the Greater Golden Horseshoe (GGH) prepare for AVs to (1) effectively improve public services, particularly public transit; (2) utilize AVs to

improve local and regional economic vitality; and (3) minimize the risks and negative impacts for present and future applications?

1.3 Relevance and Importance

The importance of AVs should not be undermined. Not only are AVs within the public's grasps already, the technology that supports vehicular automation is developing and improving very quickly. This shortens the timeline of the release of level 5 AVs. In addition, the purchasing price of AVs will drop significantly in the future making the technology more affordable and subsequently, saturating public roads with AVs. If cities are unprepared for AVs, there could be significant consequences that may prove difficult to rectify reactively such as automobile dependency, unsustainable land development and social inequity. On the other hand, AVs have the potential to address a number of existing transportation-related issues in cities. Computers are more precise and can react faster than a human can and as a result, it is anticipated that AVs will have significant safety benefits that are tied to a reduction in automobile-related collisions. AVs may also address traffic congestion that affects many North American cities and other cities worldwide. Due to its precision, AVs may be able to flow through traffic more effectively and efficiently than its human counterpart. This further reduces travel times and subsequently, can improve human productivity.

Governments will need to know what their roles are with regards to AVs. For example, new infrastructure may be required, and policies and legislation will need to be developed or amended to accommodate for AVs. It is imperative that governments begin prioritizing AVs to understand its potential, how to maximize its benefits, how to minimize its negative effects, and its short and long-term future implications.

2. Research Method and Framework

2.1 Theoretical Framework

The underlying social theory that frames my research derives from Technological Determinism, whose major proponent is Karl Marx (Bimber 1990). This reductionist theory (reductionist being a philosophical position that suggests that phenomena and theories reduce each other to a more simple form) posits that technological changes and advancements – particularly productive technology – determines and shapes social structures and relations, as well as cultural values. Furthermore, it is believed that technological advancements are an unstoppable force, occur outside of society, and create an inevitable path that cannot be controlled by society. In this instance, technology controls society.

Technological determinism can be fragmented into Hard Technological Determinism and Soft Technological Determinism. Hard technological Determinism suggests that technological advancements are so influential that societies shape themselves around the advancement of that technology. This translates to society organizing itself to meet the needs of technology because of its efficiency, and that this organization cannot be controlled to influence the outcome, i.e. loss of free will. Jacques Ellul, in this work, *The Technological Society* (1945), posits that through a natural selection process, technology

will promote and uphold social values, morals and philosophies that will aid in advancing that technology, while other values, morals and philosophies will be lost over time. Soft technological determinism suggests that technology does influence and guide societal changes, but society has the ability to change the degree of its influence and the trajectory of the technology's advancement, i.e. there is some degree of free will. Compatibilists believe that free will and determinism can co-exist, while incompatibilists believe that they cannot. My research will be theoretically framed through the lens of compatible technological determinism. It is my belief that technology does influence the structure of society, but society can also influence its outcome. My positionality is nested in the belief that the political, social, and economic forces that the technology operates in will inherently influence how technology will mingle with society. Furthermore, the dynamic nature of society makes it difficult to assume that technology is the sole proprietor of social organization. For example, societal issues may become politically charged, which in turn affects what technologies will be developed, supported and nourished in the economy. The tensions between economic, social, political and technological forces all play a role in social organization.

This theoretical framework will guide my research by exploring how AVs will affect policy formulation, decision-making and the regulation of this new technology as it continues to progress. To some degree, society will shape itself around AVs in a manner that supports its growth.

2.2 Research Design and Methodology

A mixed-method exploratory and qualitative research design will be used to conduct this research. An exploratory approach will be used because literature on AVs and its impact on cities are limited. This positions my research at a preliminary stage with potential for further investigation by means of additional studies and research. When AVs becomes more integrated into cities, more information is available and more opportunities for in-depth investigations can be conducted. An exploratory method is particularly useful for obtaining relevant and valuable background information in a more general sense to facilitate the development of new ideas, theories and hypotheses.

The initial investigation will involve conducting qualitative research in the form of semi-structured interviews with urban planners and/or project managers from municipalities in the GTA, and from relevant representative(s) from automotive companies involved with the development of AVs. This investigation will create an understanding of current initiatives, opportunities, barriers, limitations, consequences, and future prospects of AVs for Ontario. This research sets out to conduct three to four interviews with municipalities in the GTA, automotive companies and ride-sharing companies that are developing or exploring AVs. The second investigation will be library-based and includes reviews of best practices in locations where AVs have been tested.

Municipal Participants

Participants from municipalities will be captured from each upper-tier municipality in the GTA and Toronto: the Regional Municipality of Durham, the Regional Municipality of Halton, the Regional Municipality of Peel, the Regional Municipality of York and the

City of Toronto. Participants will be selected from each municipality's respective planning and economic development department, long-range planning and policy department or transportation planning/services department. The goal of these interviews are to determine what municipalities are currently involved with in terms of AVs, particularly their policies, programs, regulations, guidance, white papers, blue papers, and any research conducted, as well as to explore opportunities and threats.

Automotive Company Participants

Since it is the automotive industry that is leading the progression of AVs, it is important that their perspectives are considered. The automotive company's economic vitality and company direction will be based on how adaptable their products will be to the built environment, how it will be integrated into societies, and by extension, their level of involvement with the development of initiatives, policies and legislation. Interviews with the automotive industry will seek to: (1) determine what will be needed from governments to better assist with the development and deployment of AVs, (2) understand market trends that guide their decision-making and business structure; in particular, will automotive companies shift from a manufacturer to a transportation service provider, (3) understand how data will be managed, and (4) determine their thoughts on the future of transportation.

The following automotive companies will be considered for my research:

- Tesla Motors
 - o Tesla is recognized as one of the leaders in the connected and autonomous vehicle manufacturing, research and development.
- General Motors Company
 - o Acquired autonomous tech startup company, Cruise Automation, and invested \$500 million into Lyft, a ride-sharing and ride-hailing service.
- Ford Motor Company
 - o Plans to launch level 4 autonomous vehicles by 2021. Partnered and collaborating with Velodyne (LiDAR sensors company), SAIPS (computer vision and machine learning company), Nirenberg Neuroscience LLC (machine vision company), and Civil Maps (3D Mapping company).
- Uber
 - o Renowned ridesharing company that plans to combine their existing service with autonomous vehicles.
- Google
 - o WAYMO, a rapidly growing high-profile autonomous vehicle program that is close to public commercialization.

3. Autonomous Vehicles Background

3.1 Overview of the History of Autonomous Vehicles

The amount of attention towards AVs in the last decade has increased significantly but the technology that enables cars to drive autonomously is not new. The history of AVs dates back to the 80ies,¹ notably from a new Defense Advanced Research Projects Agency (DARPA) initiative in the United States, and from the PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety (PROMETHEUS) in Europe.

DARPA (formerly ‘ARPA’)² was established under the U.S. Department of Defense as a research agency that acted as a driver for technological innovation. Although the initial intentions of APRA/DARPA were for militaristic defense against the Soviets, DARPA’s continued exploration of innovative technologies since 1983 under the Strategic Computing Initiative (SCI)³ later proved to have civilian uses (Roland and Shiman 2002). The most notable program that came out of SCI that has helped progress the development of AVs was SCI’s third original project, the Autonomous Land Vehicle (ALV). The ALV was the United States’ first attempt at creating a vehicle capable of basic cognitive functions, i.e. artificial intelligence, in the form of image understanding (Roland and Shiman 2002). Developing this technology proved to be challenging because it required powerful computers to make quick calculations and decisions based on input from on-board cameras. The limitations of computer technology and machines in the 70ies and 80ies (the time image understanding was being developed under the SCI) made this especially challenging.

Although there were successful tests and demonstrations with the ALV, full machine autonomy was never realized during the DARPA trials under SCI (Roland and Shiman 2002). Many would argue this was due to a lack of coordination, integration and communication within DARPA itself, as well as internal competing interests that retarded progress (McCorduck 2004). DARPA’s programs and efforts did garner attention across the Atlantic however, where it was found that European countries were also exploring AV technology. As a result, a series of conferences and exchanges between Germany and the US were conducted since 1985 through organizations such as the Society of Photographic Instrumental Engineers (SPIE), Institute of Electrical and Electronic

¹ The idea of an autonomous vehicle actually dates back before the 80ies. It is arguable that the idea of an autonomous vehicle was started and popularized by Norman Bel Geddes when he unveiled Futurama at the 1939 New York World’s Fair where Bel Geddes introduced an automated freeway. Further, Bel Geddes had made suggestions that automated vehicles will be a reality as early as the 60ies in his book, *Magic Motorways* (Bel Geddes 1940; Shelton 2011).

² Prior to 1971, DARPA was ARPA; an agency birthed by former U.S. President Dwight D. Eisenhower in 1958 to overlook developments in science and technology from militaristic concerns. ARPA was originally created to oversee space-related activities until the National Aeronautics and Space Administration (NASA) was operational to develop safeguards from space-based missile attacks from the Union of Soviet Socialist Republics (USSR). It was also created under the premise that developments in science and technology should not be left solely to the military (Roland and Shiman 2002).

³ The Strategic Computing Initiative was created primarily to compete with Japan’s technological advancements in super computers and micro-processors. There were concerns that Japan may lead the US in this field (Stefik 1985).

Engineers (IEEE) and International Federation of Automatic Control (IFAC) (Dickmanns 2002).

Europe's interest in AVs led to the creation of the PROMETHEUS project in 1986. PROMETHEUS was birthed and supported by EUREKA, an intergovernmental organization established in 1985 with a focus on synergizing research and development efforts within Europe. One year after PROMETHEUS was declared an approved project under EUREKA, Ernst Dickmanns of Bundeswehr University of Munich (UniBwM) and his team successfully developed and tested Versuchstahrzeug für autonome Mobilitat und Rechnersehen (VaMoRs) on the German Autobahn for over 20 kilometers with a top speed of 96 km/h (Dickmanns 2002). This marked the first major milestone in the development of AVs. Following VaMoRs, Ernst Dickmanns continued to perfect the AV under the EUREKA PROMETHEUS project. In 1994, Ernst Dickmanns proved his capabilities again by demonstrating the driving abilities of Versuchsfahrzeug für autonome Mobilität und Rechnersehen (VaMP) (a modified Mercedes 500 SEL) at the final presentation of PROMETHEUS on Autoroute 1 in Paris (Dickmanns 2007; Kujawski 1995). VaMP's twin, VITA II by Daimler-Benz, was also demonstrated in the same presentation in Paris in 1994 (Dickmanns 1998). In the following year, Dickmanns and his team improved on the design of VaMP and performed another demonstration. VaMP successfully drove 1,600 kilometers from Munich, Germany to Copenhagen, Denmark along freeways, accomplished a maximum speed of 180 km/h and completed the trip with 95% autonomy (Dickmanns 2007; Dickmanns 1998). VaMP and VITA II was considered to be the world's first AV at that time. Three years later, another project by VisLab, a research entity directed by Alberto Broggi and founded in the early 90ies under the University of Parma that focuses on computer vision and environmental perception,^{4,5,6} created ARGO. ARGO (a modified Lancia Thema) was the first AV to travel more than 2000 kilometers with 94% autonomy and is still considered to be the first major milestone of vehicular robotics worldwide (Bertozzi et al. 1999; Bertozzi et al. 1998; Broggi et al. 2001; Broggi et al. 1999).⁷

The successful demonstrations from DARPA's ALV, PROMETHEUS and UniBwM's VaMoRs, Daimler-Benz's VITA II, and VisLab's ARGO continued to bring attention to software engineers, mechanical engineers and government agencies. In 2003, DARPA announced a challenge, the DARPA Grand Challenge (DGC).⁸ The first Grand Challenge was a prize competition of \$1 million dollars (USD), and was held in the Mojave Desert in California, USA on March 13, 2004. A total of 106 teams applied to the challenge however, only 17 teams passed the qualifying test and were deemed eligible to attempt

⁴ <http://vislab.it/>

⁵ Ambarella, Inc. acquired VisLab in 2015. Ambarella is a video and image processing company that also have automotive-specific solutions such as cameras, sensors and computer vision.

⁶ VisLab was also involved in the PROMETHEUS project, as well as the DARPA Grand Challenges. In both instances VisLab had been working with other teams.

⁷ <http://vislab.it/pdf/Brochure-VisLab-VIDA-3.51LR.pdf>

⁸ The DARPA Grand Challenges was intended to fulfill a military mandate of having 33% of its military vehicles fully autonomous by the year 2015 (Fulton and Pransky 2004). This is likely the reason why the tests were conducted in off-road environments as opposed to urban environments. The second Grand Challenge was also an off-road competition however, the third competition was in an urban environment.

the 240 kilometer off-road course. Unfortunately, none of the qualified teams were able to complete the challenge in its entirety (the most distance completed was 11.78 kilometers from the team at Carnegie Mellon University) however, the challenge was not exactly a failure. The competition was meant to tackle two challenges with respect to AVs; the functional aspect, which includes the development of the technology itself and how well it fares in an off-road environment, and the social aspect, which includes public acceptance of AVs, government support and legislative support that would subsequently foster market support (Chen et al. 2004; Fulton and Pransky 2004; McBride 2008; Ozgunner et al. 2007; Seetharaman et al. 2006).

DARPA held its second Grand Challenge in 2005, this time with a \$2 million dollar (USD) prize that attracted 197 applicants. 21 teams emerged as finalists and unlike the first challenge, 5 teams were able to finish the course. The course itself was designed to be narrow and off-road, and the vehicles would have to be able to navigate the course entirely without human intervention, much like the first challenge. Stanford University placed first for the Second DGC with their vehicle, ‘Stanley’ (Seetharaman et al. 2006; Thrun et al. 2006). The results of the Second DGC demonstrated that the rate that AV technology was progressing was significant enough to continue exploring its development. In April 2006, DARPA announced the last of the series of the Grand Challenges, but unlike the last two challenges, this one would be held in an urban setting.

Dubbed the “Urban Challenge”, this final challenge was held on November 3rd, 2007 and built off the success of the previous two challenges. Only 35 teams of the 89 that applied to the challenge were invited to participate in the National Qualifying Event, and on November 1st, DARPA announced the final 11 teams that would be competing in the final event. The primary difference between this event and the previous two events is the setting itself. As opposed to a rugged off-road environment, teams were expected to equip their vehicles with the necessary software and hardware to successfully navigate a simulated urban environment. Vehicles were expected to successfully navigate 97 kilometers of urban roads while dodging moving targets, sensing blocked pathways, crossing intersections, traversing parking lots, and navigating areas deprived of global position system (GPS) reception. The cars were also expected to obey traffic laws and flow with other traffic that was simulated for the purpose of the competition. (Baker and Dolan 2009; Fu et al. 2008; Gindele et al. 2008; Junqing and Dolan 2009; Levinson et al. 2011; McBride et al. 2008; Ozguner et al. 2007; Rauskolb et al. 2008). The team from Carnegie Mellon University, “Tartan Racing”, and their vehicle, “Boss” (a Chevrolet Tahoe), placed first at the event with a time 4 hours and 10 minutes and took home the \$2 million dollar (USD) grand prize (Urmson et al. 2008).

After the DGCs ended in the US, a new challenge was being planned in Europe. VisLab contacted those involved in Overland, a project lead by Beppe Tenti that aims to document expeditions worldwide, and organized a large-scale 13,000 kilometer AV expedition from Milan, Italy to Shanghai, China. The expedition was intended to draw more attention towards the development of AVs in hopes of attracting more demonstration opportunities and funding programs. The expedition itself was conducted over the course of three months (July to October, 2010), and involved four fully equipped

electric Piaggio vehicles that was escorted by a convoy throughout the journey. A driver was present for each of the Piaggio vehicles in the event anything were to go awry. Unlike the DGCs, this demonstration was the first large-scale experiment with AVs on open public roads where uncontrolled variables were present such as inclement weather, other non-simulated vehicles, and potential road-side hazards. This demonstration proved to be successful as all four Piaggio vehicles made it to the destination. The demonstration also gained the media and scientific attention it had hoped to get. The project has been dubbed the “VisLab Intercontinental Autonomous Challenge” (VIAC) and at that time was considered the next latest milestone in AV technology (Broggi et al. 2012).

3.2 Expectations for Autonomous Vehicles in the Near Future

Automobile manufacturers today are investing a significant amount of resources into developing AVs. Some automotive companies have officially announced target dates for their AVs. Ford Motor Company’s Smart Mobility plan is currently working towards building level 4 fully autonomous production vehicles by the year 2021 that will not have a steering wheel, brake pedal or gas pedal (Calif 2016). Audi AG has partnered with tech company, Nvidia corporation to bring AVs by 2020 as well (Audi USA 2017). These ambitious timelines proposed by the aforementioned automotive companies promise a lot, but it sets the bar for widespread AV deployment in cities, prompting governments to focus their attention on the integration of AVs into the urban fabric.

Other companies have not announced a definitive timeline for the release of their AVs however, they are not placing AVs in the back of their agendas either. All automotive companies have established partnerships, and continue to establish partnerships, with tech companies that are developing the hardware and software that enables vehicles to drive autonomously. For example, General Motors has partnered with Strobe Inc., a LIDAR (light detection and ranging; remote sensing) pioneer company to build AVs (Gallagher 2017). Automotive companies have also teamed together to hasten the deployment of AVs. Renault, Nissan and Mitsubishi formed an alliance, “Alliance 2022”, to bring AVs to the market by the year 2022 (Mitsubishi Motors 2017). Companies that were once not involved with the automotive industry are also working towards developing AVs. Google’s Waymo and Intel Corporation have partnered together to also develop AVs that are able to operate at level 4 and 5 autonomy (Krzanich 2017). Furthermore, automotive companies, start-ups and tech companies have already started testing AVs, even in Ontario, Canada – more on this later in section 6.3.

4. The Social, Economic and Political Impact of Transportation Technologies on Cities

In plain language, economic growth is understood as an increase to an entity's economic output or production, i.e. goods and services, over a period of time. "Economic output is a function of the capital and labour inputs used in the economy together with the efficiency with which these inputs are applied. Economic growth therefore depends on increases in these inputs and in total factor productivity (TFP)" (New Zealand 2014). Transportation therefore plays an integral role in supporting economic growth, as Eddington (2006) indicates in his report to the United Kingdom government where Eddington identifies seven micro driver mechanisms on how transport affects the economy (Eddington 2006b).

Increasing Business Efficiency	...through time savings and improved reliability for business travellers, freight and logistics operations. A 5 per cent reduction in travel time for all business travel on the road network in Great Britain could generate around £2.5 billion of cost savings: 0.2 per cent of GDP.
Increasing Business Investment and Innovation	...by supporting economies of scale or new ways of working. The 2001 change in regulations that permitted 44 tonne trucks is estimated to have saved 134m truck km, £160 million of operating and fuel costs, and 135,700 tonnes of carbon dioxide.
Supporting Clusters and Agglomeration of Economic Activity	Transport improvements can expand labour market catchments, improve job matching, and facilitate business to business interactions. Transport's contribution to such effects is most significant within large, high-productivity urban areas of the UK. London is the most significant example, adding 30 per cent to the time saving benefits of some transport schemes. Such productivity effects extend across commuter catchment areas, dropping away after forty minutes of travel time.
Improving the Efficient Functioning of Labour Markets increasing labour market flexibility and the accessibility of jobs	Transport can facilitate geographic and employment mobility in response to shifting economic activity e.g. in response to the forces of globalisation, new technological opportunities, and rising part-time and female participation in the labour market. Nationally, transport improvements are unlikely to have a large effect on the employment rate, though may do so in some local circumstances.
Increasing Competition	...by opening up access to new markets. Transport improvements can allow businesses to trade over a wider area, increasing competitive pressure and providing consumers with more choice. The UK is already well connected, so significant competition impacts are most likely to be felt from the integration of markets globally.
Increasing Domestic and International Trade	...by reducing the costs of trading. Since 1960, falling transport costs have boosted the international trade of goods by 10-17.5 per cent, raising UK GDP by an estimated 2.5-4.4 per cent. Domestic trade links are particularly important to the economic success of some urban areas e.g. the relationship between the financial services sectors in Leeds and London.

Attracting Globally Mobile Activity	...by providing an attractive business environment and good quality of life. Such effects are of increasing importance but extremely difficult to quantify. However, the strategic focus of transport policy can be guided by the survey evidence which suggests that both domestic and international transport links can be important to attracting, retaining and expanding such activity, and that there is much commonality between the transport requirements of domestic and global firms.
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Table 2. How transport impacts the economy – The seven micro driver mechanisms
 Adopted from Eddington’s 2006 publication to the United Kingdom Government, “*The Eddington Transport Study. The case for action: Sir Rod Eddington’s advice to the Government*” (Eddington 2006b).

The micro driver mechanisms provided by Eddington encompasses most – if not all – of the economic benefits transportation yield (and by extension, improvements to transportation technology and systems) however, developed countries that already have a strong transportation system may only benefit from transportation improvements on a more incremental manner such as improvements to safety, reliability, comfort and improved efficiencies such as reduced operating costs (Eddington 2006a). In contrast, a less developed country or region that significantly improves its transportation system can expect more dramatic economic growth as a direct result of greater domestic and international connectivity; improved movement of goods and services; increased investment and innovation; and overall support to economic input and output. This is historically true as we can see in Canada and the United States in the 19th century with the development of transcontinental railroads.⁹

The transcontinental railroads in Canada and the U.S. enabled urbanization inland and connected the Pacific to the Atlantic, which greatly supported economic activities. Cochran (1970) notes that the transcontinental railroads in the United States contributed to the large influx of people and their ease of movement across the country, which subsequently assisted with agriculture, resource extraction and manufacturing in the 19th century and beyond (Cochran 1970). Further, the construction period of the railway itself stimulated land speculation and real estate activities, which continued after the railroad’s completion. Improvements today to existing transcontinental railway systems in Canada and the U.S. will most likely not “revolutionize” the movement of goods, services and people across the country and impact the economy at the scale it did at the time of its inception in the 19th century, which may only leave room for improvements at an incremental level. Nonetheless, the link between transportation technology and economic prosperity is apparent in transcontinental railways, indicating that transportation technologies have a history of driving economic growth.

On a more regional scale, we see a similar trend taking place with Light Rail Transit (LRT) as we did with transcontinental railroads. Ferbrache and Knowles (2017) demonstrate how LRTs have been used as a city boosterism tool that can subsequently attract investments and spur economic activity in the city that it serves (Ferbrache and

⁹ United States: Northern Pacific Railway, Union Pacific Railway, Central Pacific Railway
 Canada: Canadian Pacific Railway, Canadian Northern Railway, Grand Trunk Railway

Knowles 2017). A city's image is important to its economic growth, and LRTs have the capability of shaping urban spaces and creating a sense of "place" that is reflective of the cultures and norms of the area that the LRT serves. LRTs, as a tool for reshaping urban space, can also be used as a precursor to urban revitalization in blighted areas however; this would require an understanding of the history and culture of the area being revitalized so that the redevelopment is still reflective of the area's character if the city wishes to preserve and uphold that area's heritage.¹⁰ Economically, LRTs as a means of city boosterism may succeed in raising the city's "world-class status", but this may not always be the case when the project is implemented as a neoliberal project (Ferbrache and Knowles 2017; Grengs 2005). When implemented strategically (typically in areas of existing high economic and social activity), LRTs can greatly support growth and economic development in that particular area. We see this taking place in North America with the establishment of Transit Oriented Developments (TODs). TODs have numerous economic benefits when used in a Transportation Demand Management (TDM) strategy that includes improved flow of traffic and by extension good and services; improved connectivity between regions; supporting clusters of economic growth and activity; improved overall productivity; and increasing neighbouring property values (Topalovic et al. 2012).

Using LRTs as a tool for boosterism and economic growth may seem rational and justified however; the way LRTs are being used and planned today may not actually improve overall connectivity and transportation system efficiency as much as it historically did. King and Fischer (2016) examines the way LRTs are being planned and developed in U.S. cities today and critiques the approach currently being used (King and Fischer 2016). Traditional streetcars were planned and developed in the early-mid 20th century in a manner that helped alleviate inner-city congestion and overcrowding by facilitating decentralization and subsequently, the development of "streetcar suburbs" (Purdy 2003; Tarr and Konvitz 1987; Ward 1964; Warner 1980). The development of lower density suburbs was especially important during the early-mid 20th century in Canada and the U.S. as inner cities faced a housing shortage and residents were faced with affordability issues (Purdy 2003). In Canada and the U.S., the federal government enacted housing policies that were designed to make home ownership possible for the average citizen (more on this later). Streetcars significantly expanded cities and by extension, greatly supported the housing and infrastructure industry; increased land speculation; increased property values and provided greater connectivity regionally (King and Fischer 2016). However, today LRTs are being planned and developed in a much more opposite manner. Instead of LRT projects facilitating the expansion of cities outwards, many LRT projects are spatially concentrated in specific areas and corridors to encourage economic growth in that particular area (King and Fischer 2016). This shift

¹⁰ It should be noted that there are social implications for urban revitalization. In the past, the term "revitalization" has been used as a euphemism for "slum clearance" to help justify the destruction of undesirable neighbourhoods. While proponents may argue that the results of such a process justifies the means, opponents may argue that the fragmentation of communities and the displacement of residents is far more damaging to the city itself as it can potentially erase important history and that subsequently makes it more difficult to recreate a sense of place that is unique and reflective of culture and history. The work of Jane Jacobs is one widely known example of the potential detrimental effects of urban revitalization under the modernist planning dogma (Jacobs and Epstein 2011).

towards spatially planning LRTs is not exactly reflective of the traditional transformative effects LRTs once had, and this is mostly due to external forces such as funding structures; existing planning policies and guidelines; meeting targets and visions; and political priorities. It would appear then that the role of urban expansion and decentralization that streetcars once had were passed on to another transportation technology; the personal automobile.

The automobile's role in economic development largely involves supporting not only the automobile and automobile-related industries (e.g. mining, manufacturing, mechanical engineering and electronic technologies), but also through the development of road infrastructure, supporting the housing industry and improving overall urban connectivity.

The car that revolutionized transportation in the early 20th century, the Ford Model-T, was introduced to the public in 1908 and was constructed using an assembly line style of production that significantly reduced production times and manufacturing costs (Dearborn 2012).¹¹ As a result, more people were able to afford a personal vehicle, which in return fueled the growth and success of the automotive industry and by further extension, other supporting industries as well. However, the Model-T did more than just enhance existing industries that are directly related to the manufacturing and production of automobiles; the automobile made transportation much more efficient and as such, enabled people to move out of the inner city and into the city's peripheries faster than streetcars were able to facilitate historically.

One of the aftershocks felt in Canadian cities in the years following the end of the Second World War were overcrowding that primarily stemmed from a lack of housing stock, and unaffordability. This is evident in Toronto, as Purdy (2003) explains:

“... A 1943 study [conducted] by economist OJ. Firestone of the housing difficulties of the lowest two-thirds by income among renters in Toronto showed that only 6.4 percent were paying less than 20 percent of their annual income in rent. In 1947, housing researcher Humphrey Carver found that the 12 percent of low-income households that made less than \$1,000 a year were paying more than 40 percent of their income in rent. At least 10,000 families lived in overcrowded conditions of more than one person per room or in dilapidated dwellings. By war's end, 30,000 families in the city were "doubling up," with two or more families sharing a dwelling intended for one family” (Purdy 2003, 460-61).

To address the issue of overcrowding and housing unaffordability, the Canadian government launched a series of housing-related programs intended to get the housing market rolling.¹² Of the many initiatives started by the Canadian government, the

¹¹ Due to the efficiency of the assembly line production method, a Model-T originally cost \$850 but over time as a result of Henry Ford's production innovations, the Model-T could be bought for as little as \$260 (Dearborn 2012). To compare, today that would have cost an estimated \$18,500.00 and \$5,600.00 CAD respectively (Inflation calculations sourced from the Bank of Canada (bankofcanada.ca)).

¹² It should be noted that the housing-related programs and incentives that were launched post WWII assisted middle-income earners more than it low-income earners in terms of home ownership. However, the low-income earners were not forgotten as the government also launched a series of affordable housing initiatives under Canada's National Housing Act (NHA). The 1949 NHA Amendment and the 1964 NHA Amendment sought to increase the public housing stock (Hulchanski 2004; Miron 1989; Smith

initiatives that assisted with home ownership were mortgage insurance (introduced under the 1954 National Housing Act Amendment) that allowed Canadian to place a 5% minimum down payment on a house instead of 20%, and the Assisted Home Ownership Program (AHOP) under Canada Mortgage and Housing Corporation (CMHC) later in the 70ies (Miron 1989).^{13, 14} The intention of the Canadian government with these programs were to address the housing problems that Canada faced, e.g. inner city overcrowding and poor living conditions, by pushing for home ownership however, the success of these programs relied on the co-relation between the housing industry and the automobile.

As a result of the policies enacted by the federal government in the mid-20th century, a demand was created for homeownership but in order for the housing industry to meet this demand there needed to be a way to make living in the city's peripheries viable. Public transit could not have been a feasible solution in this instance because of the amount of time and money needed to expand public transit outwards, but the personal automobile was a perfect solution. By enabling the driver of the automobile to easily and quickly traverse between city and suburb (and even between suburb and suburb), the housing industry was able to flourish. This trend of suburban sprawl was further fueled by zoning restrictions that essentially favoured homogenous developments as opposed to mixed-use developments. This resulted in the development of suburbs that needed to maintain a relationship with the inner-city for its services, employment, retail and other life necessities. Lastly, high capacity roads needed to be created to connect the city and suburb, so this period of urban transformation was also characterized by the planning and construction of highways. All issue regarding sprawl aside (Peiser 2001); it is evident that the automobile supported economic growth by supporting the housing industry and by necessitating the construction of infrastructure.

Further, the relationship between investments in transportation and economic development has been well documented and explored (Banister and Berechman 2003; Banister and Berechman 2001; Banister and Thurstain-Goodwin 2011; Berechman et al. 2006; Fogel 1979; Hall 1993; Hess and Almeida 2007; Lakshmanan 2011; Salim et al. 1999; Weisbrod 2008;). Robert William Fogel (1979) estimated a welfare loss where transportation costs would have decreased approximately 5% in GDP if the US did not create a national railway network and instead relied on other means of transport instead in the 19th century (Fogel 1979). Fogel's work emphasizes the crucial role of transportation in early US urbanization and economic development through trading that may not have taken place at the pace and scale that it did if it were not for federal funding in transportation infrastructure. In addition to the ability to move goods and people, Glen Weisbrod identifies four ways in which transportation improvements can affect economic

1968), but due to the flak public housing received, the Canadian government adopted social housing instead under the 1973 NHA Amendment and completely abandoned public housing in 1978 (Sewell 1994; Smith 1981).

¹³ Canada Mortgage and Housing Corporation (CMHC) is a Crown Corporation that was created by the Government of Canada in 1946 (formerly known as Central Mortgage and Housing Corporation) to act as Canada's housing authority to support Canadians with their housing needs. CMHC still exists today and retains much of its originally intended responsibilities.

¹⁴ The Assisted Home Ownership Program ensured that Canadian would not pay more than 25% of their income on housing in an effort to encourage home ownership (Smith 1981).

growth: “(1) by establishing new forms of trade among industries and locations, (2) by reducing cargo loss and enhancing reliability and existing trade movements, (3) by expanding the size of markets and enabling “economies of scale” in production and distribution, and (4) by increasing productivity through access to more diverse and specialized labor, supply and buyer markets” (Weisbrod 2008).

The work of Joseph Berechman et al. (2006) takes the discussion of transportation and economic development one step further by examining the relationship between transportation capital development and economic growth at municipal, county and state levels using three models: production function model, a lagged model, and a spillover model (Berechman 2006). The results indicate that not only does a positive relationship exist; there are spillover effects into neighboring areas from transit infrastructure. Furthermore, the approach of Berechman et al. differs from traditional economic studies that examine economic growth as an increase in GDP, GNP, production of goods, and exchange of goods. The work of Hess and Almeida (2007) echoes Berechman where it was found that properties located near transportation infrastructure experienced an increase in real estate value, as well as an increase in population within the area (Hess and Almeida 2007). Similar results were also found in a study of highway infrastructure and economic development by Salim et al. (1999).

Historically then it would appear that new transportation technologies have shaped commerce, policies and societies in the past, so it is fair to anticipate that AVs may have similar impacts as well.

5. The Promises and Benefits of Connected and Autonomous Vehicles

New technologies are typically speculated and given premature assumptions regarding its capabilities and benefits; this is not new and AVs are no exception. This is not to say that the speculations are incorrect (they may just be exaggerated) however, since AVs are still relatively new and not entirely integrated into cities yet, there is no real way to confirm the promises and benefits of the technology at any scale. This section will explore the promises and benefits of AVs and attempt to establish an understanding of the level of impact AVs will have on cities and governments.

5.1 The Promises of Autonomous Vehicles

The development of new technologies is motivated by a need for a solution to a particular problem, or a need or desire to enhance what already exists. It is not entirely unusual for new technologies to be placed on a pedestal and have its capabilities bolstered by its creators however, we must be careful when listening to these promises as the new technology can be over bolstered. This section will look at the two most touted promises that have been given to AVs: safety and efficiency.

5.1.1 Improved Roadside Safety

Arguably the most touted promise of AVs is a reduction in the number of roadside accidents resulting from more accurate and dependable computers replacing humans. This has been shown true in currently existing driving assist technologies such as precollision systems. Kusano and Gabler (2012) examined the macroscopic benefits of precollision systems using computer simulations based on a sample of 1,396 collisions and tested each collision with different combinations of precollision systems. The results indicate that the presence of precollision systems in a motor vehicle can significantly reduce the number of collisions, reduce collision severity and reduce the number of injured people involved in the collision (Kusano and Gabler 2012). Although this is indicative that technology, when used effectively, can improve roadside vehicular safety, there are a number of concerns regarding the capabilities of AVs improving safety, at least in the near future.

When we consider the long-term horizon of a fully autonomous transportation network, AV technology is currently at its infancy. There have been significant improvements in AV technology in the last two decades however, the software and hardware is not yet capable of full reliable autonomy. One of the most challenging limitations on reaching full reliable autonomy in the near future is determining how AVs can function safely in urban environments that house many unpredictable scenarios and changing variables from humans such as jaywalking pedestrians, sporadic lane changes from non-autonomous vehicles and cyclists merging in and out of traffic. These human-computer interactions have not yet been perfected and pose a great deal of risk and challenges when first deploying AVs on the road.

“Autonomous vehicles will have to interact with the human drivers of other vehicles. A car that is too polite or too rude will disrupt traffic flow at the very least, and perhaps indirectly cause more significant safety problems. Cutting human drivers out of the picture is likely to take many years while market

penetration of fully autonomous technology ramps up” (Koopman and Wagner 2017).

In order to ensure that AVs are safe enough to coexist with humans, there must be a level of trust from humans in the technology itself. This trust will stem from humans being able to understand the technology in order to better predict the AV’s actions and intentions. An operator of a non-autonomous vehicle is capable of interacting with humans through various means of communication such as eye contact and hand gestures. Without some form of comprehensible communication from CAVs, humans may become unsure of what the actions of a particular AV may be. This may result in humans acting in a manner that they themselves believe is comprehensible or understandable to a AV, even though it may not be.

Because humans are unpredictable, it is also equally important that the technology itself is not brittle but rather self-adaptive (Lemos et al. 2013). A self-adaptive system is capable of making decisions based on changing input data that will vary greatly from what was experienced during testing. It is inherently impossible to test AVs in every scenario that could take place in reality so designing a system that is capable to self-regulate is important for continuous development in AV safety. The challenge then would be to develop the appropriate software and hardware to make this possible. This has already been attempted in 2010 by the Technical University of Braunschweig under the Stadtpilot Project. The Technical University of Braunschweig developed Leonie with the intention of testing the first AV in a live urban environment. After taking consideration of the lessons learned from the DARPA Grand Challenges, Leonie made its first public debut On October 8th, 2010 along a route that belongs to the Braunschweig town ring from Hans-Sommer-Strasse to Hamburger Strasse and back (Nothdurft et al. 2011).

It is well understood that it is much more beneficial to test AVs on-road as opposed to a testing-only approach (Butler 1993) however, despite efforts to increase the number of hours of on-road testing for AVs; it may actually be unrealistic to develop super-dependable AVs. Nidhi Kalra and Susan Paddock (2016) found that despite rigorous testing of AVs, it may take hundreds of years for AVs to demonstrate their reliability in terms of safety in comparison to human vehicle operators (Kalra and Paddock 2016).

“The results also show in parentheses the number of years it would take to drive those miles with a fleet of 100 autonomous vehicles driving 24 hours a day, 365 days a year, at an average speed of 25 miles per hour. For example, one can ask, “How many miles (years) would autonomous vehicles have to be driven (row 2) to demonstrate with 95% confidence their failure rate to within 20% of the true rate of (column A) 1.09 fatalities per 100 million miles?” The answer is 8.8 billion miles, which would take 400 years with such a fleet” (Kalra and Paddock 2016).

Despite the calculations made from Kalra and Paddock, continuous advancements and innovation in AV technologies may decrease the amount of time an AV will need during testing to prove its safety capabilities. Furthermore, there are cooperative actions that governments and automotive companies can begin doing to hasten the development of AV technology.

As mentioned, real on-road testing of AVs is more beneficial than just testing alone. As such, it is imperative that governments allow for automotive testing on public roads in a manner that can help assist with technological advancement. Similar to what was planned for Leonie in Braunschweig, Germany, governments can designate specific roads or even entire zones for AV testing. However, there are a number of considerations to keep in mind regarding public safety. The pedestrians that occupy the space designated for AV testing will need to be informed that the road/area will have AVs operating within it and that occupants of the space should be cognizant of the presence of AVs. Signage and general public announcements can be effective here. Further, AVs should have highly visible markings on them to indicate that they are AVs. Depending on what the automaker requires, governments may even consider designating specific lanes for AV operation, such as in the outer lane, within bus rapid transit lanes (BRT), or high occupancy vehicle lanes (HOV). This will allow easy identification of AVs and make their presence more predictable. However, the designation of specific spaces for AVs may be more beneficial in the early stages of testing. As technology progresses and is proven to be reliable, AVs will most likely need to be integrated into public traffic for more advanced testing to further improve AV technology. This progression of testing methods is known as evolutionary testing (WuLing et al. 2016). The role of governments here is to continuously collaborate with automakers to determine how they can best assist in progressing AV technologies in a manner that is beneficial to both parties. Furthermore, governments and automakers should be cognizant of the interdisciplinary nature of AV safety (Koopman and Wagner 2017). In addition to governments and automakers collaborating with each other, each will also have to collaborate with their own internal departments, branches and groups to best improve safety.

5.1.2 More Efficient Transportation Systems

More advanced vehicular functionalities that will improve a transportation system's efficiency will require installing smart infrastructure onto public roads. Smart infrastructure itself is a broad term that can apply to a number of urban infrastructure types such as smart energy grids and smart water systems. In terms of transportation, smart transportation systems are formally known as Intelligent Transportation Systems (ITS) (Glancy 2015; Gottbehut 2016; United States 2015). One component of an ITS is Roadside Units (RSUs) (Milanes et al. 2012b; Naranjo et al. 2006).¹⁵ RSUs are equipment (e.g. sensors, lasers, cameras, radar and global positioning systems) designed to collect local and/or global information regarding traffic in the surrounding environment, and then transmitting that data wirelessly to other devices. RSUs can be retrofitted into the existing infrastructure, which makes it versatile in its application. Furthermore, RSU are required to improve the wireless connectivity between vehicles; an integral aspect of Connected Vehicles (more on this later) (Sou and Tonguz 2011).

The local or global information gathered by RSUs can be sent to a designated control station for analysis. After the data has been analyzed, the processed information can then be transmitted wirelessly to vehicles capable of receiving and utilizing that information.

¹⁵ Other components of an ITS includes smartphone application (e.g. public transit applications that provide real-time information on schedules and routes), intelligent traffic lights that dynamically change according to demand, toll booths, railway crossing systems and

The data will subsequently influence the decision-making of that vehicle, such as rerouting around a congested road due to a collision. This method has been tested before under the AUTOPIA program with success (Milanes et al. 2012b)¹⁶. At this point, the vehicle is not only autonomous but it is also connected; generally known as Connected Autonomous Vehicles (CAVs), or Connected Vehicles (CVs) for those non-autonomous vehicles (Glancy 2015). Vehicles today, even those that are not autonomous, can still be considered CVs. A CV by definition is a vehicle that is equipped with technologies that are capable of connecting to other devices within the vehicle itself (e.g. smartphones and GPS devices), and/or devices, networks, applications and services outside of the vehicle (e.g. other CVs, RSUs, satellites, and internet servers) (Uhlemann 2015). With the use of sensors and onboard computers, Adaptive Cruise Control (ACC) (vehicular cruise control that increases or decreases speed based on the leading and following vehicle) is one example of vehicle connection that we currently have today that doesn't require establishing a connection with other vehicles or infrastructure.

How a CV connects with the world can be split into three communication categories. (1) Vehicle-to-Infrastructure (V2I) communication or Roadside-to-Vehicle (R2V) communication refers to a CV communicating with the surrounding infrastructure or RSUs to gather and interpret traffic data in order to make driving decisions (Hasan et al. 2013b). (2) Vehicle-to-Vehicle (V2V) communication refers to a CV communicating with other vehicles primarily to improve overall safety and efficiency by better coordinating driving actions between vehicles on the road (Godoy 2015). V2V communication is based on decentralized wireless ad-hoc networks that are created by CVs using V2V communication whereby each vehicle acts as a node. This forms networks known as vehicular ad-hoc networks (VANETs), which is principally similar to mobile ad-hoc networks (MANETs). V2V communication has the potential to improve roadside safety and traffic efficiency however, there are a number of challenges such as weak signal strength and packet interruptions (Yang et al. 2004). (3) The last form of vehicular communication combines both aforementioned communication systems. This is known as Vehicle to Vehicle to Infrastructure (V2V2I) communication, and will require a using a "super vehicle" that can handle both forms of communication (Miller 2008).

There is evidence that CVs can improve overall transportation efficiency. Won et al. (2017) examined the possibility of using V2V communication to reduce phantom traffic jams (traffic jams that are amplified like a wave in stop-and-go traffic) using simulations and real traffic data. Their data suggests that V2V communication can reduce the severity of traffic jams, especially with higher market penetration rates of CVs, i.e. more CVs on the road (Won et al. 2017). Ubierno and Jin (2016) simulated the mobility and environmental improvements of V2I communication using three different car following models. Their results indicate that V2I can improve mobility, especially at higher market penetration rates (Ubierno and Jin 2016). Similar results were also found in another study by Talebpour and Mahmassani (2016) where both AVs and CVs are examined. Their

¹⁶ "The AUTOPIA Program is a research group belonging to the Centre for Automation and Robotics (CAR) of the Spanish National Research Council (CSIC) and the Technical University of Madrid (UPM)" (Godoy et al. 2015). AUTOPIA's primary role is the development of driving aid systems, particularly with AVs (Milanes et al. 2012a).

analysis and simulations indicate that both AVs and CVs can improve traffic stability and throughput. It was also found that AVs have more potential in reducing congestion and increasing throughput compared to CVs. Market penetration was also considered and was found that a higher market penetration would yield increased benefits (Talebpour and Mahmassani 2016).

Most research regarding the ability of AVs and CVs in terms of improving traffic efficiency is done through simulations, which suggests that more on-road testing and research is required to better understand the effectiveness of AVs and CVs in the short and long term. For now, it is evident that there will be no significant transportation improvements in the short term since simulations and analyses indicate that benefits become apparent as market penetration increases and roads become more saturated with AVs, CVs and subsequently CAVs.

5.2 The Benefits of Autonomous Vehicles

CAVs have not been widely implemented into the urban fabric yet which leaves little to no data regarding its benefits to cities in terms of transportation and planning. Nonetheless, there are a number of anticipated benefits that CAVs will bring. This section will discuss three widely anticipated benefits of CAVs: the reclamation of public space, enhancing existing mass transit systems, and shifting to carbon neutral mobility. Other potential benefits of CAVs are also discussed.

5.2.1 Reclamation of Urban Space

It is speculated that CAVs will liberate urban space that was once used for vehicular parking. This anticipation stems from the idea that CAV's will be able to self-navigate to-and-from destinations, which will make parking at the destination itself redundant. The idea that CAVs will reduce parking in cities also stems from the idea that CAVs will never be parked since it can always be in service. The logic behind these assumptions are reasonable however, there are a few of things to consider that may challenge the accuracy of these speculations.

To start, an owner of a CAV will likely not send their CAV home once their destination has been reached. By doing so, the owner of the CAV will have to wait for their vehicle to return back to the disembarked location to retrieve the owner one s/he wishes to leave. While this may be fine for fixed schedules such as a work schedule (the CAV can be requested to arrive at a certain time accurately even within traffic; it would just depart earlier) this removes any "on-demand" aspect of the car itself if the owner requires an immediate ride. The on-demand aspect of car ownership (immediate accessibility) is a key motivator for car ownership in the first place for many people, so it is unlikely that an owner of a CAV will purposely make their CAV not immediately accessible for themselves. Furthermore, sending the CAV back-and-forth between destinations adds unnecessary mileage for the vehicle itself.

Regardless, there are opportunities to reduce vehicular parking in urban areas with CAVs. It is estimated that a typical privately used car is only in operation for roughly one hour per day (Iglinski and Babiak 2017). Not only is this an inefficient use of the vehicle when

considering cars as an asset, parking provisions are also required to store all of the vehicles that are not in use. This parking demand becomes even more problematic in highly urbanized areas where available land is limited.

CAVs will be able to improve parking by self-navigating to designated parking garages that are equipped for CAV parking once the passenger has departed the vehicle. This makes it possible to reduce the number of curbside parking spots in urban areas however, consideration should be given to the space once used for curbside parking as it may be designated for CAV pick-up and drop-off in the future. Nonetheless, it is possible that future parking provisions in the city will only be available in parking garages as CAVs become more common on roads. The total number of parking garages may even decrease if car ownership decreases. Furthermore, when CAVs become electrified (Electric Connected and Autonomous Vehicle (ECAV)), the demand for petrol will decrease, which will subsequently reduce the number of petrol stations within cities. Petrol stations may be completely sold in the real estate market and the land repurposed, or they may be converted to ECAV charging and parking stations. In the short term, on-street parking may be strategically reduced but not eliminated completely as it is unlikely that parking spaces will be removed while there are still non-AVs operating on the road.

Even though CAVs may restructure urban parking and help reclaim some urban space, CAVs may not reduce parking demand in general if car ownership rates remain the same or increases. A city with a 100% AV modal share and a 100% car ownership rate will generate a similar amount of parking demand as a city with 0% AV modal share and 100% car ownership rate; car ownership rates remain the same thus parking demand for personally owned vehicles remains the same. A significant amount of urban space may be reclaimed when car ownership decreases and shared transportation becomes the norm. This leads to another investigation regarding car ownership trends and the growth of shared transportation services, which are both discussed later in Section 5.3.1. In short, if cities become more reliant on shared transportation services, then car ownership will decrease subsequently leading to unused vehicular parking spaces that can be reclaimed.

5.2.2 Enhancing Existing Transportation Systems

The City of Toronto and the cities within the GTA are struggling to manage transportation demand in terms of reducing congestion and increasing public transportation ridership. Although public transportation as a mode of travel has increased in Southern Ontario Census Metropolitan Areas (CMAs) (Table 3) many people still rely on their personal vehicles to complete entire trips when going to work. CAVs present an interesting opportunity to help increase public transportation use.

One inherent drawback of public transportation is that it cannot permeate every neighbourhood to a point where commuters can easily access public transportation shortly after exiting their home or place of work. Public transportation networks are designed in a manner that balances political, economic and social demands where political and economic factors typically weigh the most. Furthermore, it would be financially impractical to plan a public transit network that penetrates deeply into every

neighbourhood with frequent transit service unless the demand is present, otherwise it would be unsustainable.

Ontario CMA	Modal Share (%) Public Transit (2006)	Modal Share (%) Public Transit (2011)	Change (%)
Oshawa	7.9	8.5	+0.6
Toronto	22.2	23.3	+1.1
Hamilton	8.7	9.3	+0.6

Table 3. CMAs in Southern Ontario and their corresponding modal shares.

Source: Statistics Canada¹⁷

The lack of accessibility to public transportation for many neighbourhoods in Toronto and the GTA creates what is known as the “first mile and last mile” (FMLM) problem.¹⁸ In transportation planning FMLM is a two-part term where the first mile refers to a commuter’s trip prior to reaching a public transit facility, e.g. transit hubs, bus stops, LRT stops and subway stations, and the last mile refers to the trip from the public transit facility to the commuter’s final destination (Figure 1).

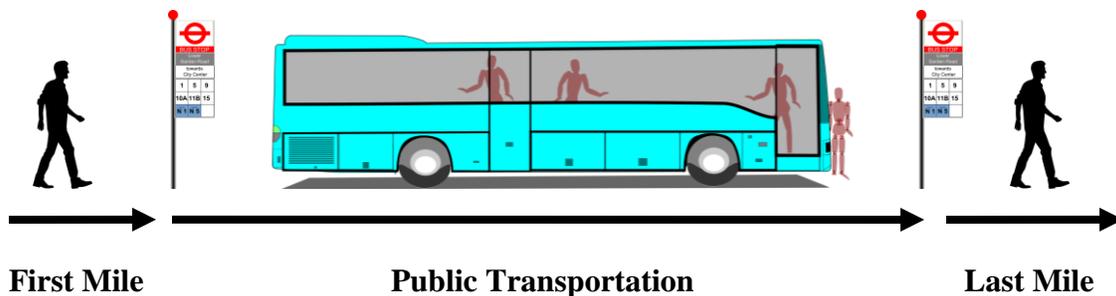


Figure 1. First mile and last mile illustration.

The first mile is the trip to a public transportation facility, such as a bus stop. The last mile is the trip after departing the public transportation service and reaching the final destination. The first or last mile of a trip may be completed by other modes of transportation such as walking, cycling or driving a car. More complex trips may also require the use of mixed modes of transportation such as public transit, cycling and walking.

The challenge for transit authorities is making the first and last mile for a commuter easy, comfortable and fast, otherwise commuters may simply drive their car to their final destination all together. Current efforts of making the FMLM easy include installing bicycle parking facilities at transit hubs, which also help promote the use of active transportation; network optimization to better serve communities with local transit and to

¹⁷ http://www12.statcan.gc.ca/nhs-enm/2011/as-sa/99-012-x/99-012-x2011003_1-eng.cfm

¹⁸ In terms of transportation, FMLM is a term that was originally used by logistics services (known by them as “last-mile logistics”) that refers to the delivery of goods from a facility or hub to its final destination. Understanding last-mile logistics is important to logistics companies because it amounts to a large portion of overall freight costs (University of Delaware 2009).

improve efficiency; and providing vehicular parking at transit hubs. The provision of parking at transit hubs has been quite successful with GO Transit in Ontario. Visit any GO Station during rush hour that provides vehicular parking and you will find many occupied parking spaces. Of course, at a municipal scale it is not always possible to provide parking at every transit hub due to the amount of space that is required (not to mention the cost of construction and future implications), so how can the first and last mile be addressed in highly urbanized areas where real estate is constrained?

CAVs may assist with the FMLM problem with public transit however; having CAVs available to the public may not significantly increase public transit ridership. There is no doubt that CAVs will be able to transport commuters easily, safely, comfortably and quickly to a transit facility, but what stops the commuter from taking their CAV to their final destination? Considering the transportation efficiencies that CAVs provide, will the travel patterns of CAV owners change? Will a commuter who typically drives to their final destination suddenly decide to drive to a transit hub instead because they have a CAV? Unless there are incentives, disincentives or policies in place that would steer CAV owners to include public transit in their daily commutes, travel patterns of car owners may not change even if they own a CAV.

How CAVs will be able to address the FMLM problem and increase public transit ridership will depend on how governments and transit authorities deliver transportation. Mobility as a Service (MaaS) (also known as Transportation as a Service (TaaS)), describes an evolutionary shift of a government's provision of public transportation; from an independently provided public service to a partnered service between public and private entities. Private shared mobility services (discussed in detail in Section 5.3.1) that may later acquire platoons of CAVs may partner with public transit providers to help address the FMLM problem. MaaS would provide commuters with on-demand transportation that would take them to any requested public transit service. The alternative to MaaS would be governments purchasing their own fleet of CAVs and integrate them into their public transit systems in a similar fashion however, the initial capital costs (as well as any subsequent costs such as maintenance and operation) of such a maneuver may make this far from being financially strategic.

In Europe, MaaS has been given a lot attention since the 2014 European ITS Congress that was held in Helsinki, Finland. The result of 2014 Congress was the creation of Europe's MaaS Alliance in 2015, an organization that consists of a consortium of public and private transportation entities that work towards creating a common approach to MaaS (MOBiNET 2015).¹⁹ The MaaS Alliance supports a number of MaaS pilots throughout Europe; serving as a valuable point of contact for examples of best practices. Kamargianni et al. (2015) discusses some examples of where MaaS has been implemented in Canada, Europe and the USA (Table 4) (Kamargianni et al. 2015). The programs identified by Kamargianni et al. (2015) differ from each other based on what each service provides, as well as what each service's level of integration is.

¹⁹ <https://maas-alliance.eu/the-alliance/>

Name	Place	Integrator	Integration Level**						Modes Included
			1	2	3	4	5	6	
Communauto + BIXI + Public transport + local Taxi	Canada	Communauto (car sharing)	x						Bike share, car share, rail, public transport, taxi
SBB + Mobilty + Publibike/ Quickbike	Switzerland	SBB (rail)	x						Bike share, car share, car rent, rail
STIB + Cambio	Brussels, Belgium	Cambio (car sharing)	x	x					Car share, rail, public transport, taxi
Hannovermobil	Hannover, Germany	Ustra (public transport)	x	x	x*	x			Car share, car rent, rail, public transport, taxi
EMMA	Montpellier, France	TAM (public transport)	x*	x	x	x	x*		Bike share, car share, rail, public transport
Smile	Vienna, Austria			x	x	x			Bike share, car share, car rent, rail, public transport, taxi
Moovel	Germany	Moovel (application)		x	x*	x			Bike share, car share, car rent, rail, public transport, taxi
SHIFT	Los Angeles, USA	SHIFT (all modes)		x	x	x	x	x	Bike share, car share, car rent, public transport, valet
UbiGo	Gothenburg, Sweden	CLOSER, Lindholmen Science Park AB (research)		x	x	x		x	Bike share, car share, car rent, public transport
Helsinki Model	Helsinki, Finland			x	x	x		x	Bike share, car share, car rent, rail, public transport, taxi, on-demand transportation

* Partial Integration

** 1: Cooperation only in terms of providing discounts for combined subscriptions

2: Ticketing integration

3: Payment integration

4: ICT integration

5: Institutional integration

6: Mobility packages

Table 4 – Summary of integrated mobility services around the world.

This table illustrates where MaaS has been implemented in Europe, Canada and the USA along with its level of integration based on what each service features. This table serves as a point of reference for further investigation on how MaaS has been implemented in different countries. Further investigations on the services illustrated above can shed light on how MaaS can be implemented elsewhere, such as Toronto and the GTHA.

Adopted directly from Maria Kamargianni, Melinda Matyas, Weibo Li, and Andreas Schäfer’s technical report titled, “*Feasibility Study for "Mobility as a Service" Concept in London: FS-MaaS Project - Final Deliverable*” (Kamargianni et al. 2015).

The success of MaaS programs varies as there have been failures in the past. In Helsinki, Finland, a pilot MaaS program named “Katsuplus” was terminated in 2015 after 3 years of its trial operation. Katsuplus was developed by the Helsinki Regional Transport Authority (HRT) and Split Finland Ltd. on the foundation of prior research conducted by Aalto University from 2007-2010. While the service itself was a success in terms of customer feedback and technological stability, the service ended due to budget constraints that were outlined in HRT’s budget proposal, 2016-2018 (Rissanen 2016).²⁰ Katsuplus was given a €3.2 million budget, which not only restricted the size of its operation (both geographically and in terms of fleet size), but that budget also pushed the pilot into a financial deficit (Table 5) (Hensher 2017).

Katsuplus	2012	2013	2014	2015	2012-2015
Operating revenues	3,000	62,700	321,800	507,900	895,400
Ticket revenues	2,600	61,700	319,200	507,700	891,200
Other revenues	400	1,000	2,700	200	4,300
Purchases of services	-316,800	-1,521,400	-2,750,200	-3,233,000	-7,821,400
Operating costs	-164,200	-1,004,000	-2,186,400	-2,626,600	-5,981,200
Other purchases of services	-152,600	-517,400	-563,800	-606,400	-1,840,200
Personnel expenses	-119,600	-276,100	-256,100	-256,000	-907,800
Other expenses	-15,500	-12,700	-10,600	-1,500	-40,300
Depreciations	-1,600	-11,100	-13,200	-13,200	-39,100
Net income	-450,500	-1,758,600	-2,708,300	-2,995,800	-7,913,200

Table 5 – Katsuplus’ financial breakdown, 2012-2015.

Adopted directly from Kari Rissanen’s 2016 report titled, “*Katsuplus – Final Report*” (Rissanen 2016).

What is atypical about Katsuplus in contrast to other MaaS services is that Katsuplus operates autonomously. This pilot project not only demonstrated the applicability of adopting a MaaS approach to transportation in Helsinki, it also demonstrated the capabilities of autonomy in transportation alongside MaaS. In North America, pilots that test the marriage of AVs and MaaS are also being explored. Uber is currently testing AVs in Toronto,²¹ Navya has launched an autonomous shuttle in Michigan,²² and Olli has been tested in Washington.²³ Keeping the Katsuplus experience in mind, determining how to make AVs and MaaS financially feasible should be an important consideration. With respect to finances, Chong et al. (2011) proposes an AV testbed that focuses on

²⁰ https://www.hsl.fi/sites/default/files/uploads/katsuplus_slides.pdf

²¹ <https://www.thestar.com/news/gta/2017/10/27/uber-testing-autonomous-cars-in-toronto.html>

²² <http://ns.umich.edu/new/multimedia/videos/24923-driverless-shuttle-service-coming-to-u-m-s-north-campus>

²³ <http://www-03.ibm.com/press/us/en/pressrelease/49957.wss>

addressing the FMLM problem while remaining economically sustainable (Chong et al 2011).

The topic of MaaS is quite a large one and I encourage investigating MaaS further to determine how MaaS can improve transportation systems in specific areas however, such an investigation exceeds the scope of this paper. What should be considered here is how CAVs will affect implementing MaaS strategies. CAVs can greatly enhance existing transportation systems by addressing the FMLM problem however, should governments purchase their own fleet of CAVs, or should governments partner with existing shared mobility services when implementing a MaaS strategy? In the case of Katsuplus, the cost of owning and operating a fleet of AV vehicles was not sustainable however, in the future when CAVs become more inexpensive, owning a fleet of CAVs may be reasonable.

5.2.3 Improved Fuel Efficiency

CAVs alone have the potential of reducing carbon emissions because they may be designed and built smaller in terms of physical size, and because they are able to operate more efficiently due to computer automation. The two biggest determinants of achieving better vehicular fuel economy is decreasing the amount of mass that is needed to move (the total weight of the vehicle), and decreasing rolling resistance. Since CAVs will be able to reduce the number of roadside accidents, smaller vehicles can be manufactured in place of larger more bulky vehicles thus reducing weight, and the following distance between each CAV on the road can also be reduced thus decreasing aerodynamic drag (Folsom 2011, 4-5). More efficient control of vehicles will also lead to a reduction in carbon emissions. Human drivers are less consistent with driving behaviours as opposed to computer-controlled vehicles. Erratic braking, rapid acceleration and idling in congested traffic (congestion that is created by human drivers) are not representative of eco-driving principles that contribute to an increase in fuel consumption and carbon emissions. Applying eco-driving principles has the potential to reduce fuel consumption by 10-20%, and computer controlled vehicles will be able to apply eco-driving principles at all times if they are programmed to do so (Barth and Boriboonsomsin 2009).

The development of more fuel efficient CAVs will also come from a restructuring of fuel economy testing procedures from governments. Mersky and Samaras (2016) found that AVs can have a considerable impact on fuel economy however, without restructuring fuel economy testing procedures, manufacturers may not aim to create the most fuel efficient AV that they are capable of producing since AVs can naturally meet minimum emission testing requirements fairly easily (Mersky and Samaras 2016). Furthermore, it is also worthwhile to consider the electrification of CAVs in the future (as mentioned in Section 5.2.1) as this will significantly reduce carbon emissions in cities all together. However, mass adoption of EVs will place an increased demand on a city's energy supply, which should be a future consideration for municipalities.

5.2.4 Servicing People that are Unable to Drive

Statistics Canada conducted the Canadian Survey on Disability (CSD) in 2012 to better understand the scope of disability in Canada. A number of disability types were identified and studied (Table 6).

Disability Type	Percentage
Pain	9.7
Flexibility	7.6
Mobility	7.2
Mental/psychological	3.9
Dexterity	3.5
Hearing	3.2
Seeing	2.7
Memory	2.3
Learning	2.3
Developmental	0.6
Unknown	0.3

Table 6 – Prevalence of disability type.

Adopted directly from Statistics Canada’s Canadian Survey on Disability fact sheet (2013) titled, “*Disability in Canada: Initial Findings from the Canadian Survey on Disability*” (Canada 2013).

13.7% of Canada’s adult population reported having a disability. Many people that reported having a disability also reported having more than one disability at the same time (Canada 2013). The province of Ontario recorded having 1,651,620 persons with disabilities in 2012, representing 15% of Ontario’s total population of 10,727,900 at that time (Statistics Canada 2015). The survey results are published for each of the disability types identified in Table 5.²⁴ The “Supports” section of each published report illustrates the met and unmet needs of Canadians with disabilities. Two supports have been chosen based on the support’s relevance to transportation and CAVs and are tabled below for each disability type (Table 7). Data regarding transportation and disability types can also be found in the “Employment” section of the disability reports. Specific employment barriers have been selected and tabled for each disability type (Table 8).

Disability Type	Getting to Appointment and Running Errands		Moving Around*	
	Needed help, not received (%)	Needed help, received (%)	Needed help, not received (%)	Needed help, received (%)
Pain	19.6	24	5.1	6
Flexibility	23.3	27.2	6.3	8.8
Mobility	23.8	30	6.8	8.1
Mental/psychological	No information available			
Dexterity	27.5	30.1	9.1	10.2
Hearing	No information available			
Seeing	53.8% **			

²⁴ www.statcan.gc.ca/cgi-bin/IPS/display?cat_num=89-654-x

Memory	34.8	29.7	9.3	11.1
Learning	No information available			
Developmental	40.6	34.1	No information available	
Unknown	No information available			
<p>* The report defines “moving around” as a person’s ability to move around their home. It is possible that a person experiencing difficulty moving around their home may also experience difficulty moving around outside their home.</p> <p>** The CSD report for seeing disabilities does not provide information on the prevalence of help received with getting to appointments and running errands for people with visual impairments.</p>				

Table 7 – Prevalence of met and unmet needs for two support variables for each disability type related to transportation.

Source: Statistics Canada’s Canadian Survey on Disabilities, 2012 reports. Each report can be obtained from: www.statcan.gc.ca/cgi-bin/IPS/display?cat_num=89-654-x

Disability Type	Accessibility Issues (%)	Lack of Specialized Transportation (%)
Pain	No information available	
Flexibility	No information available	
Mobility	No information available	
Mental/psychological	No information available	
Dexterity	No information available	
Hearing	No information available	
Seeing	19	No information available
Memory	No information available	
Learning	13.4	10.7
Developmental	No information available	
Unknown	No information available	
<p>The numbers provided in this table “Excludes those who retired more than five years ago, those who retired voluntarily, and those who stated they had never worked but that their condition did not limit the amount or kind of work they could perform.</p>		

Table 8 – Prevalence of employment barriers related to transportation for each disability type.

Source: Statistics Canada’s Canadian Survey on Disabilities, 2012 reports. Each report can be obtained from: www.statcan.gc.ca/cgi-bin/IPS/display?cat_num=89-654-x

The data presented in Tables 6 and 7 sheds some light on the relationship between disabilities and transportation however information is limited. For example, people

experiencing pain, flexibility and mobility issues required assistance getting to appointments and running errands however, only 24%, 27.2% and 30% of the people experiencing pain, flexibility and mobility issues received assistance, respectively (Table 7). People with a learning disability also indicated that accessibility issues (13.4%) and a lack of specialized transportation (10.7%) prevented them from obtaining employment (Table 8). It should also be noted that any missing information on Tables 6 and 7 is not representative of an absence for a transportation need. Furthermore, it is not assumed that every disability has a transportation need. Consideration should also be given to the percentage of people that have multiple disabilities. For example, 54.9% of people with a mental health-related disability reported to also have a mobility-related type of disability.²⁵

The specific relationship between disabilities on transportation has not been quantified or qualified in the CSD disability reports, so we can only guess that each disability has the potential to prevent someone from adequately navigating their respective urban and/or rural environment to some degree. CAVs present an opportunity to help service people with disabilities by providing an on-demand and tailored transportation service. Responses to the CSD revealed that assistance was provided to people to persons with disabilities that typically came from family and friends. For example, among the people with a flexibility-related disability receiving assistance with everyday activities, “two-thirds (66.0%) of those with flexibility disabilities received some help from family members living with them and 43.0% received some help from family members who were not living with them. Help with everyday activities came from other sources as well. For example, among those who received some assistance, 28.5% of adults with flexibility disabilities also indicated receiving help from a friend or neighbour, 21.5% paid an individual or organization for help, and 13.9% reported receiving help from an organization free of charge” (Canada 2016).

The type of assistance that is provided to people with disabilities is unknown, but if transportation is one form of assistance that is provided, CAVs will be able to help people with disabilities regain some or all of their independence by improving their overall mobility over long distances. CAVs can also help service young and elderly people who are unable drive or who do not have access to a vehicle. Unfortunately, Statistic Canada lacks data that specifically explores the relationship between age groups, transportation mode share and transportation demand.

5.3 What Remains to Explore

This section will discuss what is still not fully known or understood about CAVs. Further investigation on the subsequent subsections below will enhance our understanding of the impact of CAVs.

²⁵ <http://www.statcan.gc.ca/pub/89-654-x/2015001/tbl/tbl04-eng.htm>

5.3.1 The Effect of CAVs on Future Travel Patterns and Behaviour²⁶

Transportation technology has historically changed the way people travelled however, it is still unknown how CAVs will affect travel patterns and behaviour, particularly car dependency and car ownership. Car dependency and ownership are important considerations as it determines how cities will be managed and planned, especially if creating more sustainable cities is an important goal. Although car ownership and car dependency share a strong relation, it is important to acknowledge that they are separate terms. It is possible to not own a car but remain dependent on cars for travelling, and vice versa.

Currently, many cities in North America are supporting more sustainable modes of transportation, i.e. public transportation and active transportation, in an effort to curb car dependency. This is done by deploying strategies designed to reduce the use of personal cars such as vehicular parking strategies, designating HOV lanes, restructuring taxes and even adopting new urban design principles such as New Urbanism.²⁷ Despite these efforts, many people living in the GTA are still dependent on their personally owned vehicles for mobility, and this dependency is likely a result of an established path dependency from previous planning practices and policies, and from the historical cultural embedding of cars. The path dependency that has led to car dependency today in North America's can be traced back to the mid-20th century. Economic needs, utopian visions of cities, advertisements and propaganda are all contributing factors that set a path dependency for car dependence today.

As discussed in Section 4 of this paper, the work of Sean Purdy (2003) explores Canada's housing affordability problem in the years following the end of World War II. Purdy illustrates the experiences of low-income families and sheds light on unaffordability and overcrowding in Canadian cities. (Purdy 2003). To help stimulate the economy, the housing shortage was exploited by making home ownership among low(er)-income families a possibility. Thus, in 1946 CMHC was created and a number of policies and initiatives that were geared towards strengthening the housing market were created such as mortgage insurance. Now that families were able to afford a house, housing demand increased. This subsequently stimulated economic growth by directly supporting the home building industry, and by indirectly supporting other related industries such as infrastructure construction and the manufacturing of goods such as home appliances and furniture. Still, residents of these new homes had to travel between their suburb and the city for services and employment. Since public transportation could not expand at the same rate as suburbanization, the automobile industry boomed due to an increased demand for car ownership. Here we see the start of the path dependency that led to car dependency today; the rapid construction of homogenous suburbs and the over-reliance

²⁶ The private organizations that this section makes reference to have been chosen based on their popularity in North America. This section does not intend to endorse any specific service, nor was any sponsorship made.

²⁷ For a comparison of sustainable urban forms, see: Jabareen, Yosef Rafeq. "Sustainable Urban Forms. Their Typologies, Models, and Concepts." *Journal of Planning Education and Research* 26. (2006): 38-52.

of personal cars to travel due to the absence of alternative transportation options. While the relationship between suburb and car is arguably the biggest factor that created car dependency today, there are other factors that helped root car dependency even further.

Two other supporting agents that also embedded car dependency and car ownership in North America in the mid-20th century include (1) the creation of a car culture through advertisements that pivoted around the marriage between automobiles and suburbs, and (2) the government's support in highway infrastructure. The former was perpetuated by suburban housing developers and automotive companies where terms that resonated well with the public such as "The American Dream", "freedom", "family oriented", and "quality of life" were used in advertisements to add sentimental and symbolic value to cars and suburbs. Essentially, a new lifestyle was created and sold that focused on house and car ownership that subsequently gave birth to a car-centric subculture. This cultural embedment still persists today. The latter was influenced by modernist planning principles that typically favoured (among other urban design principles) the development and placement of large arterial highways into the urban fabric, as well as wide arterial roads. In North America, we have witnessed this in the past in New York with Robert Moses, "The Highway Man", where Moses erected many bridges and highways that were often at the expense of the health of communities and mass transit (Caro 1974; Fitch 1997). In Toronto, we have also witnessed something similar with the construction of Ontario's 400 series highways, the Don Valley Parkway and the Gardiner Expressway that penetrates the city. The highway boom eventually came to an end in Toronto around the 70ies with the cancellation of the Spadina Expressway that subsequently drove Toronto into political reform where top-down planning was no longer the standard, and public accountability was given more attention (Robinson 2011). However, by this time path dependency had already been set in Toronto, and car dependency continued to rise as mass transit attempted to "catch up" with the rate of urbanization, population growth and transportation demand.

Considering the historical trends that led to car dependency today as discussed above, it is still unknown whether car dependency and car ownership will decrease in the future even after CAVs become widely available to the public. CAVs may not actually reduce car dependency if homogenous suburbs continue to be developed, sprawl is not contained, highway infrastructure is favoured, and the pre-established automobile-centric subculture continues to be nourished.

On the other hand, a recent phenomenon has emerged known as "peak car" or "peak travel" that has been observed in developed cities since the 90ies. Peak car is understood as a stagnation or decline in distance travelled, particularly with personal cars. Peter Newman and Jeff Kenworthy (2011) discuss six possible factors that contributes to peak car, which are: hitting the Marchetti Wall, growth in public transportation, reversal of urban sprawl, aging cities, urbanization and the rise in fuel prices (Newman and Kenworthy 2011). A comparative study conducted by Kuhnimhof et al. (2013) that examines travel trends in Germany, France, Great Britain and the United States in two eras (one before 1990 and one after) extends Newman and Kenworthy's discussion where it was found that travel demand by drivers is the leading variable that influences peak car

in the United States (Kuhnimhof et al. 2013). The findings of Kuhnimhof et al. (2013) echoes that of Adam Millard-Ball and Lee Schipper (2011) who studied passenger travel trends in 8 industrialized countries (including the United States). Millard-Ball and Schipper found that private vehicle use has actually declined in most of the countries they had examined (Millard-Ball and Schipper 2011).

While the exact cause of peak car is unknown, Millard-Ball and Schipper suggests that travel time constraints, income elasticity and infrastructure investments contribute to this phenomenon (Millard-Ball and Schipper 2011). Fluctuations in car ownership levels may also contribute to peak car. Factors that influences a changes in car ownership levels include changes to lifestyle, geospatial contexts, financial constraints, availability of parking, mass transit availability and even sensitivity to the environment, i.e. carbon offsetting (Christiansen et al. 2017; Clark et al. 2016a; Clark et al. 2016b; Jiang et al. 2017; Lee-Gosselin 2016; Potoglou and Kanaroglou 2008; Ritter and Vance 2013). There is also an age dimension related to car ownership that should be considered as it may shed light on peak car. Studies that focus on the relationship between car ownership and age found that young adults are less likely to own a car, which can contribute to peak car (Belgiawan et al. 2014; Kuhnimhof et al. 2013; Kuhnimhof et al. 2012; Sivak and Schoettle 2012). For example, Oakil et al. (2016) studied the determinants of car ownership in the Netherlands among young adults and suggests that urbanization and household composition influences car ownership rates (Oakil et al. 2016). This makes sense because services and employment are far more accessible in terms of distance in highly urbanized areas where many young adults live. Good accessibility to mass transit and the feasibility of using active transportation to reach a destination likely make vehicle ownership redundant in highly urbanized cities. Further, young adults living in cities may likely be living in a household composition that does not require owning a personal car.

Young adults today are less car-oriented than previous generations, and this may be due to the factors that influence car ownership discussed above, however the rise of Internet Communication Technologies (ICT) and shared mobility may be the most influential factor. Shared mobility is a transportation service that involves sharing modes of transport with other users. This form of travel has been made extremely popular in the last decade because of advancements in ICT. For cars, there are two forms of shared mobility, ride-sharing and car-sharing.

The term “ride-sharing” involves individuals sharing a vehicle with another passenger or the driver to reach a destination. “Ride-sharing” and “carpooling” have been used interchangeably however, there is a difference that should be understood (more on that later). In keeping with the theme of modern technology, one example of a ride-sharing service is Uber Technologies Inc. Uber provides a “matchmaking” service between people willing to drive, and people looking for a ride who are also willing to pay a service fee. Uber has arguably evolved into a taxi-like service (ride-hailing)²⁸ since its

²⁸ Traditional ride-hailing take places on the streets itself whereby passengers physically wave down a taxi. Modern ride-sharing services, such as Uber, digitize this process through software, which blurs the line between ride-hailing and ride-sharing. Perhaps the two aforementioned terms may be consolidated in the

inception however, Uber is still a self-proclaimed ride-sharing service. Caution should be applied when referring to ride-sharing services such as Uber since ride-sharing is not exactly carpooling even though ridesharing services can be used in a carpooling manner.

²⁹ In Ontario, under the *Public Vehicles Act, R.S.O. 1990, c. P.54*, a “car pool vehicle” is considered as such if:

- 1. No fee is charged or paid to the driver**, owner or lessee of the motor vehicle for the passengers’ transportation, except an amount to reimburse the expenses of operating the motor vehicle as described in subsection (2) on a non-profit basis.
 - 2.** The driver does not take passengers on more than one one-way or round trip in a day.
 - 3.** The owner of the motor vehicle, or the lessee of the motor vehicle if it is leased, does not own or lease more than one motor vehicle used as described in subsection (2) unless the owner or lessee is the employer of a majority of the persons transported in the motor vehicles.
- (*Public Vehicles Act, R.S.O. 1990, c. P.54*, [s. 1, ss. 4]).

Car-sharing involves an individual temporarily renting a vehicle that others may also rent upon return. An example of car-sharing today that is atypical to traditional car-sharing services is, Turo.³⁰ The difference between Turo and other car rental services is in the ownership of the vehicle itself. With Turo, customers are renting other people’s own personal vehicle(s) whereas with a traditional car rental service, customers are renting company-owned vehicles. This service (and others like it) widens the car-sharing market to the general public whereby anyone can place their own personal vehicle(s) for rent, and this in turn makes it easier for people to access a vehicle at any given time.

The ride-sharing and car-sharing industry (collectively belonging to the ‘Shared Economy’) may potentially decrease car ownership in the future however, it may not reduce car dependency; it may actually do the opposite and increase car dependency if shared mobility becomes the dominant service choice for transportation within cities. With newer generations of young adults becoming increasingly involved with ICT and different values regarding cars and lifestyles are adopted, car ownership may decline but car dependency may remain the same or even increase.

The importance of peak car, the new generation of young adults and ICT is its impact on transportation and land use planning (Thomopoulos et al. 2015). If cities are experiencing

future however, existing ride-sharing services may want to monopolize the term and label it as its own industry.

²⁹ Uber offers flexibility in terms of scheduling for its drivers. Unlike a traditional taxi driver, Uber drivers do not operate on a fixed schedule; drivers may start and stop their service at any time. In addition, Uber drivers have the liberty of selecting their passengers based on the passenger’s. This flexibility allows an Uber driver to pick up passengers that are seeking to travel in the same direction as him/herself. For example, an Uber driver that is routinely visiting a grocery store for personal needs may turn on his/her Uber service to see if anyone else is seeking to travel in that direction as well. Although the Uber driver is getting paid for the service of picking up another passenger, this is principally ride-sharing. However, it should be noted that Uber drivers typically do not operate this way and instead operate much like a taxi by constantly roaming streets looking for passengers.

³⁰ Founded in 2009, Turo is a car rental service that allows anyone to rent out their own personal vehicle(s). <http://www.turo.com>

a reversal of sprawl and a decline in car ownership, then demand on local and regional transportation systems will increase. This is a good sign of a healthy and burgeoning city however, where public transit fails to adequately serve residents, residents will likely search for alternatives. ICT makes alternative choices of transportation highly accessible, and ICT resonates well with young adults and future generations. As a result, public transit providers may be competing with shared mobility service providers. This competition may become more challenging as CAVs breach reality. In the future it may be entirely possible that ride-sharing services will purchase entire fleets of CAVs and operate entirely without drivers, which could reduce fares on the consumers end. Ride-sharing services that plan to offer a bus-like service (the driver can pick up other passengers on the way, similar to that of public transport) may further result in fare reductions. Fare reduction combined with an increase in transportation efficiency from CAVs may disrupt public transit providers' operations. Furthermore, this disruption may also be compounded by car-sharing whereby car-sharing services satisfies one-off vehicular needs when ride-sharing or public transit would not be a viable transportation option.

What implications do CAVs and ICT have for governments? In order to compete with the private shared transportation market will governments have to purchase fleets of CAVs as well in order to keep public transportation relevant? If so, how can the government's own fleet of CAVs keep public transportation relevant? Will governments partner with shared mobility services instead to provide MaaS? How should the partnership between public transit providers and private shared mobility services be arranged? What policies will be needed to ensure a healthy transportation system when CAVs start to saturate roads? The answers to these questions remain fairly unknown however; the future impact from investments, policies and actions that will be made today should be carefully scrutinized to avoid creating an unfavourable path dependency. Governments will have to be cognizant of CAVs' impact on the physical environment, social trends, travel trends, the health of communities, and the future of public transportation.

According to Metrolinx, there are two possible directions that could take place regarding the evolution and impact of CAVs and shared mobility on cities and governments (Table 9) (Metrolinx 2016). Both directions represent two ends of a spectrum where municipalities will fall somewhere in between.

	Highly Managed Development	Organic Development
Shared/on-demand mobility services	Would be limited to only those services that complement public transit in a first-mile/last-mile function, increase per vehicle occupancy, or satisfy demand in areas that are difficult to serve with transit. However, the banning of all other shared/on-demand services would be difficult to enforce, and some may continue to operate outside of regulations. Service providers that partner with government would have to	Would be allowed to operate freely with little oversight. With automation, no driver will be needed, so even individuals would be able to put their privately owned CAVs up for sharing, which could introduce concerns around safety, security and liability. Driven by profit, pricing may motivate single-occupant vehicles, and longer travel distances, resulting in more driving overall.

	enter formal contractual relationships with government to operate, making it a challenge for many service providers, especially smaller ones. Long procurement processes for retaining services would make solutions outdated by the time they are implemented, limiting innovation.	
Public transit	Would continue to provide broad network coverage, with higher-order or frequent service parts of the network acting as the backbone. Certain elements of shared/on-demand services would be incorporated into the public transit service offering, such as through microtransit in areas that have lower demand.	Would only remain in corridors where transit is much more competitive in travel time and convenience, or where intense demand results in autonomous vehicle congestion. Other parts of the network, particularly those with low levels of service, would have ridership cannibalized by emerging modes that are more demand responsive.
Mobility management	Would be a central part of government's role within transportation. Service pricing, road user charges, and taxes would play a fundamental part in motivating desirable people and goods movement behaviour. Government may consider taking a one-window approach for personal mobility, by integrating all pricing on one platform, but may face challenges in operating and maintaining such a system.	Would be difficult to coordinate with low government oversight. Pricing of services would be based purely on competition, with little regard for network, or societal impact. Modes and services that generate the most profit would be motivated, while low-impact modes such as transit, walking and cycling would be less emphasized.
The built environment	Would continue to be shaped by policies that encourage higher densities. Mobility management mechanisms would contribute to discouraging widespread acceptance of longer commutes as a result of CAVs. With the expectation of increased first-mile last-mile and autonomous services, stations would be re-developed to address the diminished need for parking at stations.	Would return to a trajectory of sprawl as CAVs would enable commuters to travel longer distances without the stress from driving and lost productivity. Transit station parking would largely become obsolete as most riders will be dropped off by CAVs, but without a plan for how to deal with these structures, many will sit vacant. Similarly, without plans to accommodate the increase in drop-offs at stations, station access will be a challenge, and perhaps a deterrent to transit use.

Table 9 – Highly managed development direction and organic development direction for CAVs and shared mobility.

Information directly adopted from Metrolinx's *New Mobility Background Paper. Full Report, Technical Paper 4 to Support the Discussion Paper for the Next Regional Transportation Plan*, 2016 (Metrolinx 2016).

A highly managed approach to CAVs and shared mobility in Ontario can hinder innovation and detract investments into municipalities, but public transit will likely remain relevant and competition free. Governments would also be more involved with transportation management in a highly managed environment. A purely organic approach will allow private industries to flourish economically and drive innovation further because regulations are more lenient or non-existent, but a lack of regulation may result

in increased competition between public transit providers and private ride-sharing companies, an increase in the number of single occupant vehicles on roads, and sprawl. Governments will need to determine how to regulate CAVs and shared mobility in a manner that minimizes the negative impacts of over-management and under-management.

5.3.2 Data Ownership, Access, Security and Privacy

“Data is truly the new currency of the automotive world.”

- Brian Krzanich (Krzanich 2016)

The CEO of Intel Corporation, Brian Krzanich, estimates that AVs will generate roughly 4 terabytes of data per day from the AV’s arsenal of on-board units (OBU).

“In an autonomous car, we have to factor in cameras, radar, sonar, GPS and LIDAR – components as essential to this new way of driving as pistons, rings and engine blocks. Cameras will generate 20-60 MB/s, radar upwards of 10 kB/s, sonar 10-100 kB/s, GPS will run at 50 kB/s, and LIDAR will range between 10-70 MB/s. Run those numbers, and each autonomous vehicle will be generating approximately 4,000 GB – or 4 terabytes – of data a day” (Krzanich 2016).

The data that AVs produce will be an extremely valuable resource in the future because it can provide insight and push innovation for many industries such as insurance (setting rates and calculating risks), automotive (improving safety and efficiency), and potentially even the entertainment industry (entertaining passengers in AVs) (Devlin 2016).

Governments also benefit from the data AVs generate. Emergency response units can quickly and accurately determine where crime or roadside accidents occur and respond in a timely manner. Traffic flow data can assist with future planning and development of transportation systems to meet mobility demands, such as the development of transit hubs and rail lines in strategic locations. Future growth and urbanization trends can also be more accurately determined which will assist with future infrastructure development and redevelopment planning. The data generated by AVs can also provide insight on where public transportation service is strong or weak in cities, which will allow transit authorities to optimize transit systems accordingly.

Big data raises a number of big questions. (1) Who has ownership of the data? (2) Who will have access to the data? (3) How will data be secured? (4) How will data privacy be managed? The answer to these questions has not been definitively determined yet, but some exploration has been conducted. At the rate that technology is developing it is imperative that questions regarding data are addressed in the near future.

Data Ownership

At this point it is unknown who will own the data that AVs will generate. Data ownership may fall into one of these three scenarios. (1) The automotive company that created the CAV will own the data since they are the producer of the CAV that is generating the data in the first place. (2) The owner of the vehicle owns the data since the CAV is their legal property so any data that it generates are rightfully the owner’s property as well. (3) Through legislation and policies, governments will own the data for reasons that they deem necessary. There is a fourth scenario however and it involves public and private

entities collaborating to manage the data. This fourth scenario treads on the discussion on data access.

Data Access

Cities around the globe are looking at data management through a new lens, known as “open data”. According to the Government of Canada, Open data is “defined as structured data that is machine-readable, freely shared, used and built on without restrictions” (Canada 2017b). The Government of Canada further explains that data will be available in its entirety, will be provided under terms that will permit reuse and redistribution, and that there will be no accessibility barriers for anyone wishing to access the data (Canada 2017b). The concept of open data is to enable and support innovation, growth, transparency improve services and progress research, among other benefits by making data openly available. This requires data that is collected and owned by governments, citizens and private industries to be openly accessible (Ahlgren et al. 2016). Having an open data portal is an important element of smart cities (Ojo et al. 2015).

In Europe and the USA, open data initiatives have been explored. Ojo et al. (2015) discusses four European cities and one U.S. city with open data initiatives and what the outcomes of having data openly available have been. Ojo et al. (2015) concludes that big data in an open environment can potentially benefit cities in terms of the economy, education, energy, environment, governance, tourism and transportation (Table 10) (Ojo et al. 2015).

Domain	Impact Patterns
Economy	<ul style="list-style-type: none"> - Creation of marketplace for society relevant applications; - Availability of data products and services based on city operational data and; - Scaling up the adoption of open data innovations across city functions through tools provision.
Education	<ul style="list-style-type: none"> - Availability of innovative digital services for the education domain.
Energy	<ul style="list-style-type: none"> - Availability of innovative digital services for the education domain.
Environment	<ul style="list-style-type: none"> - Greener environment.
Governance	<ul style="list-style-type: none"> - Better information sharing. - Open innovation for co-created services - Open engagement in policy and decision-making - Interoperation within city-network.
Tourism	<ul style="list-style-type: none"> - Co-created services based on available open data.
Transportation	<ul style="list-style-type: none"> - Better City Park Management; and - Shorter transit time for commuters.

Table 10 – Summary of impacts of open data initiatives on cities.

Table adopted directly from Adegboyega Ojo, Edward Curry, and Fatemeh Ahmadi Zeleti’s article titled, “A Tale of Open Data Innovations in Five Smart Cities” (Ojo et al. 2015).

Cities in Canada also have started opening their data. Dong et al. (2017) discusses the types and formats of data that the cities of Calgary, Halifax, Surrey, Waterloo, Ottawa, Vancouver and Toronto provides, the various tools that open data has helped created, and the current research and data integration challenges of open data in Canada (Dong et al. 2017). While Dong et al. (2017) specifically focus on public data, the value of open public data is apparent, suggesting that the inclusion of data from private entities could further support innovation and growth.

The impact of open data initiatives on cities can be significant, suggesting further research on what type of data is the most valuable to governments, where the data should be coming from if governments are seeking to use open data to improve cities, how much data is desired for achieving any particular goal, and what data partnerships will be needed to increase the value of the open data. In consideration of CAVs, the data that it will generate may be most beneficially used if it were in an open data market for anyone to access. However, since data has been labeled as digital gold, we may have data holders who are not willing to “donate” their data to the open data market. Establishing partnerships and determining data ownership will be required to better understand the level of accessibility of CAV-generated data. Furthermore, the discussion of big data and open data treads along the path of the “Internet of Things” (IoT),³¹ and smart cities. While both IoT and smart cities are related to CAVs, such a discussion exceeds the primary focus of this paper. Regardless, further investigations on IoT and smart cities should be perused to better understand the digitization of cities and how that will affect transportation systems and services.

Data Security

The IEEE Standards Association released IEEE 1609.2 standard published under, “IEEE Standard 1609.2™2016, IEEE Standard for Wireless Access in Vehicular Environments—Security Services for Applications and Management Messages”. This manual suggests methods for improving Wireless Access in Vehicular Environments (WAVE) communication messages, i.e. the exchange of data between two vehicles or between a vehicle and smart infrastructure, as well as data encryption and data privacy. While the security algorithms and methods that will be used in CAVs mainly fall into the domain of the manufacturers of the equipment, governments will likely be expected to collaborate with manufacturers of CAVs to better understand what data security methods are being considered, how safe the proposed security methods are, and whether such a method is appropriate for mass-production and public use. In this regard, governments may be expected to collaborate with manufacturers to set and/or update security standards for data transmission and storage. Furthermore, smart infrastructure owned by governments such as traffic lights are prone to cyber-attacks (Li et al. 2016). In a smart city where a plethora of smart infrastructure is installed (more may be installed in the future to support CAVs as well), security of ITS will be just as important as data protection.

³¹ According to the International Telecommunication Union (ITU) (a special agency under the United Nations), IoT is defined as “a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies (ICT)” (International Telecommunications Union 2012).

Data Privacy

CAVs will likely collect personal and private data of the owner and passenger(s) relating to authentication, personalization and ease of use. Personal identifiers such as name, age, voice, face and fingerprints may be collected for authentication reasons. Specific locations that the CAV has travelled to will also be collected and perhaps even remembered for easier selection of destinations in the future. Location data will also be attached with dates, times, speed and specific route taken, which raises concerns at the user level; who will have access to this personal data, and for what purpose? Banking information may also be collected in a CAV if a user requests a ride from a transportation service that uses CAVs.

There are steps that can be taken to address privacy concerns with CAVs. Legislation is the first consideration with privacy as it sets the boundaries of what can be collected and used. In Canada, the *Personal Information Protection and Electronic Documents Act* (PIPE-DA) regulates what private organizations are permitted to collect and use commercially. Each province in Canada may also have provincially enacted privacy acts that, if deemed substantially similar to PIPE-DA, will apply in place of PIPE-DA (see also Canada's *Digital Privacy Act*, 2015, an amendment to PIPE-DA) (Canada 2017a). One caveat of PIPE-DA is its application to municipalities. Although provinces have authority over municipalities, the Office of the Privacy Commissioner of Canada has determined that PIPE-DA does not apply to core activities of municipalities.

“As a result, our Office [the Office of the Privacy Commissioner of Canada] is of the view that, as a general rule, PIPE-DA does not apply to the core activities of municipalities, universities, schools, and hospitals. By core activities we mean those activities that are central to the mandate and responsibilities of these institutions” (Canada 2015).

If municipalities are planning to acquire their own fleet of CAVs and use it as a public transportation service, municipalities will need to consider the legal implications related to privacy. Existing privacy laws may need to change to support municipally owned CAVs, and new legislation may also be required. On September 13, 2017, the Canadian Bar Association (CBA) held a teleconference that discussed regulatory aspects of AVs (Canadian Bar Association 2017). The CBA has not released any publications regarding this teleconference yet.

Other means of addressing data privacy include making the data that CAVs collect anonymous so that users cannot be personally identified, establishing industry guidelines that regulates the collection of data, and ensuring that users of CAVs are fully informed of their privacy rights including what type of data the CAV will collect, i.e. user consent.

5.3.3 Partnerships Needed

Establishing partnerships is crucial during the development phase of CAVs. Automotive companies are currently partnering with other companies that were once not typically associated with cars. For example, tech company, Nvidia Corporation, has developed the Nvidia Drive™ PX that is specifically designed for autonomous vehicles, and Intel Corporation has developed Intel® Go™ platform for autonomous cars as well. These

relationships are important to the development of CAVs themselves, but it is the partnerships between automotive companies and governments that will greatly accelerate the advancement of CAVs and the maximization of its potential.

Live on-road testing of AVs is more beneficial than testing through simulations or in small-scale controlled environments. The shift from simulation and controlled tests to live on-road tests and beyond is what is known as evolutionary testing (WuLing et al. 2016). Advancing CAVs will require challenging its technologies, which calls for testing in real environments that scales in complexity as the technology evolves and improves. This is where partnerships between governments and automotive companies need to be established. Such a partnership will allow automotive companies to progress CAV technologies, and it will also allow governments to better understand CAVs and prepare for its integration onto roads. What is unknown is how this partnership will be established, and what will be required from each involved party. Will there be a central organization that mediates the partnership between governments and automotive companies, or will each individual municipality have to establish its own individual partnerships? These questions also draw upon the debate of municipal cooperation versus municipal competition (more on this later in section 6.2).

Governments may also require partnerships with wireless service providers to support CV communication. CVs work on wireless communication whether the CV is communicating with other vehicles on the road (i.e. V2V communication), or communicating with the infrastructure (i.e. V2I). Vehicles communicating with other vehicles or nearby devices utilize dedicated short-range communication (DSRC) (Ansari et al. 2013). DSRC can also be used to communicate with infrastructure however; the limitations of DSRC makes DSCR the least favourable candidate for V2I communication.

Based on connectivity requirements and what is available, the three wireless network candidates for V2I communication are; (1) cellular networks, (2) Wireless Interoperability for Microwave Access (WiMAX) networks, and (3) Wireless Local Area Networks (WLAN) networks. Each network candidate has advantages and disadvantages (Table 11).

	Original Purpose	Advantages	Disadvantages
Cellular Networks (GSM, EDGE, UMTS HSPDA)	<ul style="list-style-type: none"> - Provide indoor and outdoor wireless service - Originally used to provide mobile voice service 	<ul style="list-style-type: none"> - Long range service - Infrastructure already widely deployed in urban areas; large coverage range - Able to handle high loads and demands 	<ul style="list-style-type: none"> - Requires cellular infrastructure to cover geographical areas - Low data exchange rates - Operates on licensed frequency spectrums; need to purchase to use - Potential high cost
802.16 Networks (WiMAX)	<ul style="list-style-type: none"> - To service areas where cables and wires are sparse or difficult to install 	<ul style="list-style-type: none"> - Medium-long range service - Can be deployed in areas lacking 	<ul style="list-style-type: none"> - Not widely deployed, dedicated WiMAX stations are necessary

		<ul style="list-style-type: none"> - communication infrastructure - High data exchange rate for fixed stations 	<ul style="list-style-type: none"> - Potential high cost - Low data exchange rate for mobile applications
802.11 Networks (WLAN)	<ul style="list-style-type: none"> - Provide short range indoor service only. - Originally used in buildings to connect devices wirelessly to a single network 	<ul style="list-style-type: none"> - Its short range limitation is being addressed - Becoming ubiquitous, making it potentially cost effective and having good infrastructure support - Can be used for ad-hoc networking, or infrastructure networking - Operates on free frequency band - High data exchange rate, even when the device is moving 	<ul style="list-style-type: none"> - Short range service - Not originally intended for outdoor use - Disruptions from handover between Access Points (AP)*

Information presented in this tables derives from Hasan et al.'s book titled, *Intelligent Transport Systems 802.11-based Roadside-to-Vehicle Communications* (Hasan et al. 2013b).

* Handover refers to a device disconnecting from one AP and connecting to another. In 802.11 networks, a vehicle moving between two APs may encounter a “dead zone” where the AP does not service that area geographically because of unplanned construction of APs.

Table 11 – Wireless network options for CAVs.

Information derived from Syed Faraz Hasan, Nazmul Siddique, and Shyam Chakraborty’s book titled, *Intelligent Transport Systems 802.11-based Roadside-to-Vehicle Communications*, 2013 (Hasan et al. 2013b).

The use of each of the three different network options presented in Table 11 for V2I communication has been previously explored (cellular networks (Inam et al. 2016; and Uhlemann 2017), WiMAX (Aguado et al. 2008; and Xing et al. 2008), WLAN (Hasan et al. 2013a; Hasan et al. 2010; Mertens 2008)). All three wireless network candidates are capable of individually supporting V2I communication however, research and testing has been conducted on integrating wireless networks into a heterogeneous network to serve devices (Abboud et al. 2016; Doyle et al. 2011; Lee and Lee 2013; Shafiee et al. 2011; Sivarai et al. 2011; Van Leeuwen et al. 2006; Wei and Zhuang 2010). By integrating wireless networks, inherent weaknesses can be addressed, and strengths can be exploited. It is entirely possible that CVs will use multiple networks to remain in operation, and as communication technologies continue to improve, it may also be possible that cellular networks will play a large part in V2V2I communication.

Governments may need to partner with cellular network companies to support CV functionalities. If CVs will operate on cellular networks (or in a heterogeneous network that includes cellular networks) then there will likely be a cost involved to use the cellular

network provider's frequency and bandwidth. Depending on how telecommunication companies approach CV connectivity in their networks, payment plans may become devised for users where CV owners are expected to pay to connect their CV to a cellular network. If this is the case, governments may have to partner with telecommunication companies to not only plan and build infrastructure to support CVs, but to perhaps arrange a license deal to access their private wireless frequencies. Furthermore, it is also entirely possible that automotive companies may already be partnering with telecommunication companies to hasten the deployment of CVs.

6. The Current Status in Ontario with Connected and Autonomous Vehicles

6.1 Legal and Policy

Prior to deploying and testing AVs on-road, regulations and guidelines must be in place to ensure safety and compliance with other related legislation. This section will discuss the legal and policy status of AVs in Ontario with regards to safety, authority and deployment. Insurance, ownership and license are not discussed in this section in great detail. The purpose of this section is to establish an understanding of the legal parameters that allow AV deployment and testing in Canada with specific attention to Ontario.

Federal

At the federal level, there is currently no legislation in place that directly speaks to AVs. Regarding motor vehicles in general, under the *Motor Vehicle Safety Act (1993, c. 16)*, the *Motor Vehicle Safety Regulations (C.R.C., c. 1038)* regulates motor vehicle safety and motor vehicle components in Canada. The *Motor Vehicle Safety Regulations* itself has not been amended to include AVs to date. Furthermore, there are no pending Bills under the *Motor Vehicle Safety Act (1993, c. 16)*, indicating that there are no current proposals for AV integration into Canada's federal legislative framework yet. Safety regulations proposed in the future will need to be considerate of the winter season since winter is a significant characteristic of Canadian roads.

Under section 20, subsection C of the *Motor Vehicle Safety Act (1993, c. 16)*, the Minister is granted the power to “establish and operate facilities for the testing of vehicles, equipment and components, and acquire test equipment for that purpose”. This may indicate that the Minister has the ability to designate specific areas for controlled CAV testing however, CAV technology in its current state will likely require on-road testing. Nonetheless, the Minister may in the future designate specific areas for uncontrolled CAV testing to help support the development of CAV technologies.

Canada's southern neighbour enacted a new legislation in September of 2017 titled, *H.R. 3388 – 115th Congress (2017-2018): SELF DRIVE Act*. This act grants the US National Highway Traffic Safety Administration (NHTSA) the authority to regulate AVs and to encourage its development and deployment. One interesting aspect of the *SELF DRIVE Act* is that it supersedes any State-created legislation or regulations regarding AVs that are non-identical to the *SELF DRIVE Act*, as indicated in Section 3 under the *Act*. Prior to the enactment of the *SELF DRIVE Act*, The United States Department of Transportation (USDOT) released a guiding document for AVs on September of 2016 titled, *Federal Automated Vehicles Policy*, which sets the compliance framework for automotive companies developing AVs in the USA. It is likely that the Federal Government of Canada will look towards the US Federal Government for guidance on AV policy, guideline and legislation development.

Provincial

Ontario is the first province in Canada that allows AV testing on public roads. Under Ontario's *Highway Traffic Act, R.S.O. 1990, c. H.8*, the government of Ontario created *O. Reg. 306/15: Pilot Project – Automated Vehicles* that came into effect January 1, 2016.

O. Reg. 306/15 allows owners of AVs to test AVs on highways subject to approval by The Registrar.³² *O. Reg. 306/15* establishes the framework for testing AVs in Ontario by stipulating permitted and prohibited use, as well as the approval process for testing AVs among other guidelines. Furthermore, it should be noted that although *O. Reg. 306/15* states that testing will take place on “highways”, the term “highways” is defined under the *Highway Traffic Act, R.S.O. 1990, c. H.8* to include “a common and public highway, street, avenue, parkway, driveway, square, place, bridge, viaduct or trestle, any part of which is intended for or used by the general public for the passage of vehicles and includes the area between the lateral property lines thereof; (“voie publique”)”. This means that testing of AVs under *O. Reg. 306/15* is not constrained to provincially owned highways such as Ontario’s 400 series highways or King’s Highways, but also includes roads within municipal jurisdictions.

While *O. Reg. 306/15* is a step in the right direction to prepare Ontario for AVs, *O. Reg. 306/15* is quite restrictive with its current regulations. For example, Section 7 of *O. Reg. 306/15* prescribes requirements for AVs, which includes complying with the *Motor Vehicle Safety Act (1993, c. 16)* as well as the regulations made under that Act. As discussed earlier, the *Motor Vehicle Safety Regulations (C.R.C., c. 1038)* made under the *Motor Vehicle Safety Act (1993, c. 16)* has yet to be adjusted to incorporate AVs. As a result, a ‘passenger car’ that is not equipped with a manual steering control system or motion control pedals would not be approved for testing on Ontario highways. In general, the stipulations of *O. Reg. 306/15* are:

- “This pilot is restricted to testing purposes only;
- The pilot will run for 10 years and include interim evaluations;
- Only vehicles manufactured and equipped by approved applicants are permitted;
- The driver must remain in the driver's seat of the vehicle at all times and monitor the vehicle's operation;
- The driver must hold a full class licence for the type of vehicle being operated;
- Eligible participants must have insurance of at least \$5,000,000;
- All current Highway Traffic Act rules of the road and penalties will apply to the driver/vehicle owner; and,
- Vehicles must comply with SAE Standard J3016 and any requirements of the Motor Vehicle Safety Act (Canada) that apply to automated driving systems for the vehicle's year of manufacture” (Government of Ontario 2015).

Other regulations under the *Highway Traffic Act, R.S.O. 1990, c. H.8* and the *Public Vehicles Act, R.S.O. 1990, c. P.54* such as license, insurance and convictions will likely be adjusted to incorporate AVs in the near future as well. For instance, the regulations outlined in the *Highway Traffic Act, R.S.O. 1990, c. H.8 [s. 205.15-205.25]*, regulates red light camera system evidence. If an AV is captured by a red light camera, would the driver be at fault? What would this mean for driver licenses?

³² Currently, testing of AVs under *O. Reg. 306/15* is only granted to the owner of the AV(s), who must also be the creator or converter (i.e. from a non-AV to an AV) of the AV.

Municipal

Municipalities in Ontario have the authority to pass by-laws regarding matters under their jurisdiction. Municipalities in Ontario currently do not have official by-laws in place regarding AVs. This is expected at this time since AVs have not fully penetrated the market yet however, with *O. Reg. 306/15* currently in effect, we can expect municipalities to develop by-laws and policies regarding AVs in the near future. Furthermore, municipalities will be looking at higher levels of government for further guidance prior to enacting their own policies.

York Region has acknowledged AVs and CVs in their Transportation Master Plan (TMP), meanwhile other second tier and single tier municipalities in the GTHA (City of Hamilton, Regional Municipality of Halton, Regional Municipality of Peel, City of Toronto and Regional Municipality of Durham) have yet to incorporate AVs and CVs in their TMP or Official Plan (OP). It is imperative that municipalities begin to consider and incorporate AVs and CVs in their plans and policies. Under the *Planning Act, R.S.O. 1990, c. P.13*, [s. 26, ss. 1.1] municipalities are required to update their OP every five years after the plan has come into effect. Some municipalities are nearly due for an update to their OP, which may trigger an update to their TMP as well. This presents an opportunity to include AVs and CVs into their TMP and OP, for both upper and lower tier municipalities.

SAE International

The Society of Automotive Engineers (SAE) is a global association that consists of professional engineers and technical experts in transportation technologies. SAE released its AV standard, SAE Standard J3016_201609, which standardizes AVs by providing taxonomy for AV levels of automation from level 0 to level 5.³³ This standard has been officially adopted by the US DOT to help frame the development and testing of AVs.³⁴ SAE J3016_201609 does not provide specific requirements, nor does it prescribe regulations on AV development and testing however, acknowledging SAE J3016_201609 as a global standard for AV classification will assist with clarifying the roles of drivers (if any), assist in policy and legislation development, provide a framework for specifications and technical requirements, and standardize AV language making communication across disciplines more clear among other benefits (SAE International 2016b).

6.2 Cooperation and Coordination between the Automotive Industry and Municipalities

As stated earlier, partnerships are essential to the safe and smooth incorporation of CAVs into urban environments. In acknowledgement of the rate that AV technologies are improving and the inevitable release of CAVs to the public in the near future, the Ontario Good Roads Association (OGRA)³⁵ established the Municipal Alliance for Connected and Autonomous Vehicles in Ontario (MACAVO) in 2016. This alliance is intended to

³³ http://standards.sae.org/j3016_201609/

³⁴ <http://articles.sae.org/15021/>

³⁵ The mandate of the Ontario Good Roads Association is to represent the transportation and public works interests of municipalities through advocacy, consultation, training and the delivery of identified services. <https://www.ogra.org/index.html>

partner municipalities in Ontario together to facilitate CAV research, testing and its integration into cities (OGRA 2016).

According to the OGRA, municipalities will need to make a concerted effort with other municipalities to hasten the deployment of CAVs in Ontario and to develop guidelines and policies to maximize its benefits, such as using CAVs in TDM strategies. One research participant from the OGRA expressed their frustration with municipalities hiding notes, research and information from other municipalities. This is counterproductive to Ontario as a whole when looking at CAVs holistically. Municipalities naturally compete with other municipalities however, this competition should not jeopardize the integrity of Ontario's progression towards AV development and deployment. My research participant also suggests that a standard should be applied for all municipalities, and if some municipalities are able to exceed the standard, they are able to do so. This ensures that a level of fairness is applied to all municipalities while still allowing the "superstars" to shine. Cooperation would also prevent the establishment of AV "silos" and instead, support the development of AV corridors between municipalities. This is important because AV testing on roads may not start in dense and highly urbanized areas; such an environment may be too risky for AV deployment due to complexity – not to mention the red tape. Smaller municipalities may be a more suitable candidate for initial AV testing since road conditions are less complicated and more predictable. This experience would be invaluable for larger municipalities as they prepare themselves for AV deployment in their own jurisdiction once AV technologies demand testing in more complex environments. In turn, the experiences and lessons learned from AV testing in larger municipalities could be shared with smaller municipalities that can subsequently help the smaller municipality understand the impact of CAVs on planning, economic and social matters in highly urbanized contexts.

MACAVO is not exclusive to just municipalities either. OGRA intends to recruit members into MACAVO from the automobile industry as well as any other stakeholder involved with AVs (OGRA 2016). As suggested in section 5.3.3, establishing a partnership between automotive companies and governments is crucial to driving innovation, ensuring safety, and preparing for large-scale deployments of AVs. At the time of my interview, MACAVO did not have any partnerships with members from the automotive industry however; the infrastructure requirements for CAVs may encourage automakers to reach out to governments for collaboration.

The Ontario Centres of Excellence (OCE)³⁶ launched its Connected Vehicle/Automated Vehicle (CVAV) Program in 2015 to support the growth and innovation of CAV technologies in Ontario.³⁷ In addition to academic institutions and industry leaders, the CVAV Program is also partnered with the Ontario Ministry of Transportation (MTO) and the Ontario Ministry of Economic Development, Employment and Infrastructure. The CVAV Program provides funding to projects (subject to approval) that are intended to

³⁶ OCE is Ontario's science and research organization that supports Ontario's economy by commercializing innovation, establishing partnerships, and by bridging the gap between academia and industries in a number of fields.

³⁷ <http://www.oce-ontario.org/programs/industry-academic-collaboration/cvav-research-program>

develop new innovative CAV technologies through partnerships between academic institutions and companies, municipalities and companies, or between two or more companies (OCE 2017). Funding is provided in two streams. Stream 1 is not intended for research proving feasibility, but instead focuses on the development of new CAV technologies and establishing partnerships between companies and academic institutions. Successful applicants of Stream 1 could receive a maximum of \$50,000 over the course of one year. Stream 2 is also not intended for research to prove feasibility, but it is more demanding than Stream 1. Stream 2 focuses on developing, prototyping and demonstrating new technologies, encouraging public-private partnerships, collaborating at a high level, and demonstrating the project's impact to Ontario economically, environmentally or socially. Successful applicants of Stream two could receive a maximum of \$250,000 over 18 months. Streams 1 and 2 of the CVAV Program is currently not accepting applications; the deadline to apply was August 6, 2015 for both streams. Approved projects under both streams are scheduled to finish in 2018. The success of the CVAV program supported the launch of OCE's latest CAV initiative, the Autonomous Vehicle Innovation Network (AVIN).

AVIN focuses on capitalizing on CAV's economic potential, CAV integration into transportation systems in cities, and establishing partnerships between academic institutions, governments, companies, any interested stakeholder, and the general public. AVIN consists of four on-going programs and one central hub, the latter of which consists of a dedicated team that administers, delivers and supports AVIN's programs. AVIN's "AV Research and Development (R&D) Partnership Fund" program builds on the momentum of the CVAV Program and is similar to it; two streams are offered however, funding is significantly higher. The "Talent Development" program bridges the gap between academic institutions and industries in the CAV sector to support knowledge exchange, internships and innovation. The "Demonstration Zone" program takes place on a test site in Stratford, Ontario and is intended to demonstrate new CAV technologies under live conditions, which include adhering to existing laws and regulations. The "Regional Technology Development Sites" program is intended to establish a network of technology and development sites across Ontario to support entrepreneurs and start-ups by providing them access to resources such as hardware, software, testing sites, and special equipment. Overall, AVIN is intended to establish partnerships between governments, academic institutions, industry leaders, other interested stakeholders and the general public to progress the development and testing of AV technologies for marketization.

In addition to internal partnerships within Ontario, the Province of Ontario has partnered with the State of Michigan to support AV development. In recognition of Ontario and Michigan's role as the leading automotive jurisdictions in North America, Ontario Premier Kathleen Wynne and Michigan Governor Rick Snyder met on August 3rd, 2016 to sign a Memorandum of Understanding to promote innovation and competitiveness through technological advancements, supply chain integration and developing best practices between the two jurisdictions (Government of Ontario 2016).

Municipalities seeking to establish partnerships with academic institutions and/or industry leaders of CAVs may seek partnerships through OCE's AVIN. Provincial departments are already involved with AVIN, making municipal collaboration sensible as well, but consideration should be given to how municipalities participate in AVIN. Utilizing the AVIN as a resource pool may facilitate the creation of innovation silos, i.e. municipalities developing and learning about AVs within enclosed borders. To prevent the creation of silos, Ontario and its Municipalities should consider cooperating with other municipalities as well. A partnership facilitator such as OGRA's MACAVO may be necessary to bridge the gap between municipalities and other municipalities, while still involving other stakeholders and the automotive industry.

6.3 Current Tests and Initiatives in Ontario³⁸

Since the enactment of *O. Reg. 306/15*, AVs are being tested across Ontario. Seven organizations have already been granted approval for AV testing in Ontario, which are: the University of Waterloo, the Erwin Hymer Group, Blackberry QNX Software Systems Ltd., Uber Technologies Inc., Continental AG, X-Matik Inc., and Magna International Inc. (the first three organizations that were approved for AV testing in Ontario were the University of Waterloo, the Erwin Hymer Group and Blackberry QNX) (Allen 2017). Some of the aforementioned companies are not independently developing AVs either rather; they are making the necessary components for AVs whereby the end-user would make use of the equipment as they see fit.

University of Waterloo

The University of Waterloo launched its Waterloo Centre for Automotive Research (WatCAR) Project that provides a space for automobile innovation, specifically with CAVs. Their current project is a Lincoln MKZ hybrid sedan, named "Autonomoose", which made its first debut in 2016 in Stratford, Ontario's Stratford Festival parking lot (Beitz 2016). The team behind Autonomoose intends to test the AV in various weather conditions, as well as honing in on the technology prior to testing on public roads. Autonomoose made a major milestone in autumn of 2017 as it was the first university-based team to test an AV on a public road in Ontario under *O. Reg. 306/15*. Autonomoose was tested on Colby Drive, a public road that serves an industrial and commercial area in the most northern part of Waterloo, Ontario (Caldwell 2017). The team behind Autonomoose continues to test, monitor and develop AV technologies under the WatCAR Project:

"The goal of the research team, which includes nine professors working under the umbrella of the Waterloo Centre for Automotive Research (WatCAR), is to progressively add more automated features. Specific aims of the Waterloo project include improving automated driving in challenging Canadian weather conditions, further optimizing fuel efficiency to reduce emissions, and designing new computer-based controls. The researchers will test the vehicle everywhere from city streets to divided highways as they add and fine-tune new capabilities" (University of Waterloo 2016).

³⁸ The information provided in this section derives from trusted secondary sources such as government websites and news articles from reputable media providers.

Further, Autonomoose utilizes Blackberry QNX's software platform to operate; more on this later.

Erwin Hymer Group

The Erwin Hymer Group (EHG) (not to be mistaken with one of its brands, Hymer, a recreational vehicle (RV) manufacturer) unites various RV manufacturing companies under its domain. EHG opened its Erwin Hymer Innovation Lab in Kitchener-Waterloo and is currently working with students from the University of Waterloo to develop a fully autonomous RV. This project is the first of its kind in Canada; no other company that is approved for AV testing under *O. Reg. 306/15* is seeking to develop autonomous RVs. EHG's test vehicle, a Mercedes-Benz Sprinter Van dubbed "The Roaktrek E-Trek", was first debuted with its autonomous gadgets in 2016 during OGRA's Annual Conference in Toronto, Ontario (EHG 2017). EHG's approach to autonomous RV development is to develop everything internally, from the software to the hardware, thereby maintaining absolute control over the system. The lessons and experiences learned from EHG's research and testing may be able to support the development of fully autonomous busses and other larger vehicles. Nonetheless, the focus of EHG's E-Trek is the end-user's experience with automation in recreational activities, such as camping or "RVing".

Blackberry QNX

Blackberry QNX launched its own innovation centre in Kanata, Ottawa in 2016 called the Autonomous Vehicle Innovation Centre (AVIC). Justin Trudeau attended the opening of AVIC in Ottawa and states that this centre will further solidify Ontario, and Canada at large, as the leading jurisdiction of AV software and security development (Reuters 2016). QNX is largely focusing on the software side of AVs and plans to continue to expanding the number of engineers at AVIC to develop more advanced and secure AV operating systems such as advanced driver assistance systems, and V2V2I communication (Blackberry QNX 2016; Reuters 2016). The latest demonstration of Blackberry QNX's software was seen in the Lincoln MKZ, dubbed Autonomoose, with the University of Waterloo however, the Blackberry QNX-equipped Lincoln MKZ made its very first debut during the unveiling of AVIC in 2016 (Reuters 2016). One year later on October of 2017, the autonomous Lincoln MKZ performed a live demonstration on an enclosed public roadway in Ottawa, which also marked Canada's very first on-road AV test (Wong 2017). Prior to this live demonstration the Lincoln MKZ has made other internal demonstrations, such as the parking lot demonstration with Ontario Premiere Kathleen Wynne when Kathleen visited the AVIC site in summer of 2017 (CTV Ottawa 2017).

Uber

Shared mobility giant, Uber Technologies Inc., has also started testing AVs in Ontario. Uber released two autonomous Ford Focus hybrid vehicles in Toronto on August 22nd, 2017 however, these AVs are not intended to service Uber customers rather, they are intended to conduct road-mapping tasks (Bykova 2017). The two AVs drove around the UofT campus and other surrounding areas for one week, and had a driver behind the wheel at all times as stipulated in *O. Reg. 306/15* (Allen 2017). Uber intends to refine AV technologies to ensure safety prior to freely releasing it to the public, perhaps as a

service. In collaboration with the University of Toronto (UofT), Uber has also chosen Toronto as its site for its first international research lab, taking advantage of the Toronto-Waterloo technology and innovation corridor (Robinson 2017b). Uber’s Advanced Technologies Group (ATG) now has centres in Pittsburgh, San Francisco and Toronto. Furthermore, Uber also made a multi-year pledged of \$5 million per year towards the Vector Institute, an independent non-profit research facility founded in part with UofT professor, Raquel Urtasun, that is dedicated to the development of artificial intelligence (McGillivray 2017; Robinson 2017a).

On the topic of MaaS, Innisfil, Ontario partnered with Uber On May 15, 2017 to integrate Uber into the public transportation system. Innisfil residents can call an Uber ride and enjoy a fixed rate to select destinations, while any other custom destination will also receive a \$5 subsidy under this pilot program (Table 12).

Destination	Uber Fare*	Resident Pays	Town Subsidizes
Innisfil Recreational Complex/Town Hall ‘campus node’ from:			
Stroud	\$8-12	\$3	\$5-9
Sandy Cove Acres	\$14-18	"	\$11-15
Innisfil Heights	\$9-12	"	\$6-9
Alcona	\$9-12	"	\$6-9
Churchill	\$10-12	"	\$7-9
Lefroy	\$13-17	"	\$10-14
Gilford	\$17-22	"	\$14-19
Fennel	\$13-17	"	\$10-14
Cookstown	\$21-28	"	\$18-25
Tanger Outlets	\$18-23	"	\$15-20
GO bus stop on Yonge Street and Innisfil Beach Road** from:			
Stroud	\$7-9	\$4	\$3-5
Sandy Cove Acres	\$14-18	"	\$10-14
Innisfil Heights	\$9-11	"	\$5-7
Alcona	\$9-12	"	\$5-8
Churchill	\$9-12	"	\$5-8
Lefroy	\$13-17	"	\$9-13
Gilford	\$17-22	"	\$13-18
Fennel	\$13-17	"	\$9-13
Cookstown	\$21-28	"	\$17-24
Tanger Outlets	\$18-23	"	\$14-19
Barrie South Go Train Station from:			
Stroud	\$8-10	\$5	\$3-5
Sandy Cove Acres	\$12-15	"	\$7-10
Innisfil Heights	\$14-18	"	\$9-13
Alcona	\$15-19	"	\$10-14
Churchill	\$15-19	"	\$10-14
Lefroy	\$19-24	"	\$14-19
Gilford	\$23-29	"	\$18-24
Fennel	\$18-24	"	\$13-19
Cookstown	\$27-35	"	\$22-30
Tanger Outlets	\$23-30	"	\$18-25

Innisfil Employment Area and Highway 400 carpool lot from:			
Stroud	\$12-15	\$5	\$7-10
Sandy Cove Acres	\$18-24	"	\$13-19
Innisfil Heights	\$6-8	"	\$1-3
Alcona	\$15-19	"	\$10-14
Churchill	\$15-19	"	\$10-14
Lefroy	\$19-24	"	\$14-19
Gilford	\$22-29	"	\$17-24
Fennel	\$15-20	"	\$10-15
Cookstown	\$19-24	"	\$14-19
Tanger Outlets	\$16-20	"	\$11-15

* Uber offers a number of services that vary in price. Calculations are based on the most basic service, Uber X, however, an even more economical service is available, Uber Pool.

** The GO bus stop at Yonge Street and Innisfil Beach Road was selected at random; any GO bus stop along Yonge street within the Town of Innisfil is eligible for fare subsidies.

Table 12 – Sample of the fare structure between the Town of Innisfil and Uber Technologies Inc.

The fare calculations presented in Table 11 was determined by first calculating the estimated fare between destinations under the “Destination” column using Uber’s online fare calculator. The calculated Uber fare is then subtracted with the proposed fares for trips to-and-from the specific destinations outlined in the Town of Innisfil’s proposed ridesharing transit service. This leaves the remaining balance as the Town’s subsidized cost. The report that outlines the Town’s proposed fares to-and-from specific destinations can be found in the Town of Innisfil’s Staff Report DSR-042-17 (Cane 2017). Starting destination were selected based on popular points in Innisfil.

After the town of Innisfil completed a transit feasibility study in 2015, it was determined by council after reviewing the study that implementing a fixed bus route would be too costly given the Town’s budget, and that the return on investment for a fixed bus route is not significant (Cane 2016; Town of Innisfil 2015). The Town explored other options to meet transportation demand in the Town of Innisfil, and determined that partnering with Uber to provide transportation services was the best solution, especially in consideration of resident’s input regarding their needs. The feasibility study determined that operating a single bus would cost the Town approximately \$270,000 per year, and nearly double that if the town wishes to operate two busses (Town of Innisfil 2015). The Town has allocated \$100,000 to implement Stage 1 of the program, and has another \$125,000 allocated for Stage 2 when that time comes. Stage 1 of the project was scheduled to last 6 months from that day of its implementation on May 1, 2017. Stage 2 will begin after the data collected from Stage 1 has been analyzed to better optimize the program, understand how to better manage a demand-based transportation service, as well as to explore any additional partnerships (Cane 2017). This project could set precedence in Ontario to invest into MaaS with share mobility services such as Uber.

X-Matik

X-Matik Inc. is a Toronto-based tech company that is producing add-on kits for non-AVs that will transform them into a level 3 AV. While still a small company, X-Matik intends to democratize AV technology so that it can be enjoyed by everyone, which will subsequently hasten its adoption onto roads (Nowak 2017). The kit, named LaneCruise™, is currently in its beta stage however, interested patrons are able to purchase the kit for approximately \$3,000 and test the technology themselves as part of the beta program. Unfortunately I was not able to get in contact with a representative from X-Matik to discuss how they are approaching testing and development since beta testers – citizens that have purchased the LaneCruise™ system – are unable to use the technology themselves on public roads under *O. Reg. 306/15*, unless they are granted approval to do so. I suspect that buyers of LaneCruise™ will be from approved groups under *O. Reg. 306/15*, X-Matik will partner with approved groups, and X-Matik will conduct their own tests in Ontario. Further, I suspect X-Matik will be selling LaneCruise™ to other jurisdictions outside of Canada that have less stringent regulations.

There are safety concerns with LaneCruise™, such as its lack of advanced technologies (lasers, radar and sonar), and that a small firm with limited resources (in comparison to automotive and tech giants already in the AV field) will fall behind in terms of technological development (Nowak 2017). It is likely that X-Matik will partner with another company to continue the LaneCruise™ project, which I believe is satisfying a particular yet lucrative market; converting existing cars into AVs inexpensively rather than buying a brand new AV.

Continental AG and Magna International

On July 31, 2017 two AVs departed Windsor Ontario towards Traverse City, Michigan, which marked North America's first cross-border AV test drive (Government of Ontario 2017). This demonstration involved Magna International's autonomous Cadillac ATS, and Continental AG's autonomous Chrysler 300.

“The automated driving vehicles will cross into Windsor, Ontario before going north to Sarnia, Ontario and return back into Michigan. The first cross-border demonstration of its kind, this drive allows Continental and Magna, as well as the Michigan Department of Transportation (MDOT) and the Ontario Ministry of Transportation (MTO), to test automated driving technology in a variety of settings” (Magna International Inc. 2017a).

At the end of the test, Ontario and Michigan signed a memorandum of understanding, the second of its kind, to continue to foster growth, partnership, innovation and economic development between the two jurisdictions and the Great Lakes Region at large (Magna International Inc. 2017a).

Both Magna International and Continental AG are automotive parts manufacturers that are working towards creating partnerships to deploy their AV systems. Continental AG has its own AV named, CUbE (Continental Urban Mobility Experience) and has been in partnership with BMW Group, Intel and Mobileye since June, 2017 (Continental AG 2017). Continental is a company based in Germany that has recently started working on AVs in Ontario, Canada together with Magna International. Magna International recently

released its MAX4 autonomous driving platform that can be easily integrated into any vehicle to support up to level 4 autonomy (Magna International In. 2017b). Magna International has also followed Continental AG's decision to partner with BMW Group, Intel and Mobileye in October, 2017 (Magna International Inc. 2017c). The international experiences from both companies can greatly assist with the development of AVs in Canada, and consequently, the lessons and experiences obtained here in Canada can also support the companies' own interests with regards to innovation.

7. The Challenges that Ontario will need to Overcome

7.1 Infrastructure

As of now, AVs rely on a suite of OBUs to read the environment in order to drive autonomously. Tests and demonstrations have proven the capabilities of laser, sonar, radar and cameras to navigate roads safely however, AVs may be limited in its ability to perform safely in less favourable conditions. In 2016, the first known death caused by an AV unfortunately took place in Gainesville, Florida. Joshua Brown was utilizing Tesla's Autopilot (Tesla's autonomous driving platform) one bright sunny day, when the Tesla vehicle hit a white truck that the OBUs did not detect (Yadron and Tynan 2016). It is possible that the OBUs of the Tesla vehicle failed to recognize the white truck due to the weather conditions; the sun blinded the cameras and rendered the truck invisible. Since the incident, Tesla revamped Autopilot to include more powerful processors, more cameras, and the biggest change of all, a shift from relying on cameras as Autopilot's primary sensor, to using sonar technologies as Autopilot's primary sensor (Hook 2016). We know that AVs are not perfect however, this incident raises concern about AVs performing under conditions that the OBUs are not optimized to perform well under. How will AVs perform in heavy snowy conditions that could make cameras difficult to see objects and lane markings? How will AVs be able to operate safely in rural areas where the road and the shoulder may be difficult to differentiate, and lane marking may be non-existent?

Indeed, more cameras, more sonar sensors, more lasers and more computing power may improve an AV's ability to perform safely in challenging conditions however; it may be possible that CAV-specific infrastructure may be necessary in certain urban and rural settings to ensure safety, at least until the technology ramps up to the point infrastructure assistance wouldn't be required. For example, on rural roads with limited lane markings, proximity sensors could be installed into the roadway to help guide AV vehicles wirelessly. OBUs would be capable of detecting the sensors on the ground to determine how close or how far the CAV is from the edge of the road or lane. The in-ground sensors may even be able regulate CAVs, such as retarding acceleration in construction zones, emergency response zones (such as an automobile collision), school zones, and even in areas known for high pedestrian traffic during certain time brackets. This type of system, an electronic "smart" highway infrastructure, has yet to be tested or developed, and it is unknown whether such a system is necessary, or even financially feasible. However, municipalities and automakers should at least consider that the future installation of new AV-specific infrastructure may be a required (Bamonte 2013).

To support CVs, governments will need to determine the infrastructure requirements that enable wireless vehicular communication. Existing infrastructure such as traffic lights and signalized pedestrian crossings can be fitted with RSUs to communicate with CVs however, governments will need to determine where the RSUs will be placed and how many to deploy. Chi et al. 2016 presents a model that places the least number of RSUs on roads (Chi et al. 2016). Chi et al.'s (2016) model focuses on improving traffic flow, and takes into consideration of adjacent interactions and the intersection's priority. Silva and Meira (2016) explore the use of both stationary RSUs and mobile RSU in a given

environment and found that using a hybrid approach improves overall coverage by up to 45% (Silva and Meira 2016). Governments will need to determine the best approach to deploying RSUs, which is especially important considering the capital costs of mass-deploying RSUs as it can be quite significant. Furthermore, as mentioned in Section 5.3.3, wireless communication infrastructure may also be needed to support CVs, such as additional cellular network towers, especially in underserved areas. Network robustness will be a key influence when designing a wireless network to service CVs. “The current signaling infrastructure was designed for the human driver and therefore the entire system is based on visual signals. Despite tremendous progress in computer vision, humans are still much better than machines in the perception of visual information. The only 100% reliable way of communicating signaling information to machines is via robust, secure and low latency wireless networks. Infrastructure based on wireless connectivity is inherently low cost, and offers unparalleled flexibility” (McCarthy et al. 2016). Further research on infrastructure needs and partnerships between automakers and communication service providers will be required.

Other infrastructure considerations will be the designation of AV specific lanes/roads for initial deployment and testing, the construction (or lack of) new roads, and signage. As discussed in Section 5.3.1, CAVs may increase automobile dependency, but automobile ownership may decrease due to shared mobility. This may create an opportunity to designate AV lanes on public roads if they become underutilized, but this may take time to coordinate and establish since there will be social, economic and political considerations. Furthermore, it seems as though the provincial government has the power to designate spaces for AV testing, but giving municipalities the ability to determine where AVs can be tested and deployed in their own jurisdiction may be beneficial as well since local governments have a more in-depth understanding of their communities.

7.2 Legal and Policy

In comparison to US jurisdictions, *O. Reg. 306/15* is quite restrictive albeit for safety reasons. This is understandable since AVs are still in the development stage, which leaves concerns for safe operability however, more lenient AV policies can hasten the development of AV technologies and its subsequent integration into urban environments. Furthermore, restrictive AV legislation can potentially detract investments into the jurisdiction that the legislation applies to. This is an important consideration for governments seeking to remain competitive through innovation. All levels of government in Canada will likely look towards the US for guidance on legal and policy development for CAVs. Although this may help to ensure that informed decisions are made in Canada, following the US can slow the mass deployment of AVs in Canada thus, making it more challenging for Canada to establish itself as a leader for innovation and technology.

As technology continues to improve, governments will need to stay on top of the CAV industry to ensure that innovation is not hindered. As mentioned in Section 5.1.1, evolutionary testing will be required to progress AV technologies. (WuLing et al. 2016). As such, legislation will need to adapt to the needs of automakers in conjunction to advancements in AV technologies, which can be very time consuming because of the amount of variables that need to be considered for policy and legislation development.

For example, enabling automakers to test level 3+ AVs on public roads without a human driver present, or allowing vehicles without a manual steering control system to operate on public highways will require a considerable amount of research and collaboration to draft regulations that is fair to the interest of governments and the AV industry.

Laws regarding data collection and use will need to be adjusted for CAVs. Canada's PIPE-DA, as discussed in Section 5.3.2, regulates how and when private companies are able to collect, disclose and use data. AVs are able collect personal information such as identity, travel habits, and perhaps even an individual's shopping habits. For example, data from CAVs may reveal that a particular patron frequents certain commercial establishments or areas with a reputation for niche businesses. This data can be invaluable for targeted advertisements and business forecasting for that industry. PIPE-DA (generally) stipulates that collection, disclosure and use of data without consent may only be allowed if it relates to an individual's security, national security, legal investigations, statistical research and scholarly research. CAVs may require a user's consent prior to operating the vehicle, which could essentially allow the vehicle to collect and use any data that the consent statement explicitly indicates.

Widespread deployment of CAVs will likely not take place until the legal framework for CAVs has been solidified in terms of AV testing; AV operation; data collection, use and disclosure; and privacy protection.

7.3 Auto Insurance

The automobile insurance industry is already working towards adapting their policies for CAVs however, progress is limited. According to The Insurance Institute of Canada,³⁹ the biggest challenge that the insurance industry is facing right now is determining who is at fault in the case of a collision involving an AV (The Insurance Institute of Canada 2016). Determining fault in non-autonomous vehicles involves collecting evidence on the circumstances that led to the collision, which typically focuses the attention onto the operator of the automobile however, with CAVs, this becomes challenging. In a collision involving a CAV, the operator of the automobile may be at fault (even partially) if the operator did not engage in the safe operation of the motor vehicle. This is especially true in semi-autonomous vehicles that still require an operator's attention, which would typically be the case today. For example, Tesla Motor's Autopilot, one of the most advanced AV platforms in the market today, still requires the operator to pay attention to the driving environment. In the case of a fully AV where no steering control system is in place, who is to take fault in the case of a collision? Would it be the owner of the AV simply because it is their property so they are responsible for its actions? Or perhaps it would be the responsibility of the automaker of the AV because they designed and developed the AV? Fault can also be placed on the tech companies that manufacture the OBUs and the software platform that the AV uses since the collision could be caused by

³⁹ "The Insurance Institute is the premier source of professional education and career development for the country's property and casualty insurance industry. Established in 1899, the Institute is a not-for-profit organization serving more than 39,000 members across Canada through 19 volunteer-driven provincial institutes and chapters."

<https://www.insuranceinstitute.ca/en/about-the-institute>

an error in the software and hardware's functionality. It could also be a shared responsibility, but how would the share of fault be determined? "The insurance industry needs to develop a consensus among Canadian stakeholders around the issue of legal responsibility of various parties for traffic collisions when driver assistance or self-driving systems are engaged. Moreover, it is important to establish procedures that can be applied to determine responsibility" (The Insurance Institute of Canada 2016).

Some automakers have taken the initial steps to determine fault in the case of a collision with AVs. For example, Volvo has explicitly declared in 2015 that they will accept responsibility in the case of an accident involving their AVs while the AV is in autonomous mode (Volvo Cars 2015). While this move may be a strategic business decision to demonstrate their confidence in their technology, it certainly primes the stage for insurance policy change in the future. Other automakers may follow suite in the future to assert confidence in their product to make their product more attractive to the consumer. In the end, it is the courts that will ultimately influence how AV insurance policies will change (The Insurance Institute of Canada 2016).

7.4 Transparency, Coordination and Cooperation

There have been CAV initiatives established that bridges the gap between governments, academic institutions, and industries such as OGRA's MACAVO and AVIN (Section 6.2). In addition, there are also other similar initiatives established by private companies to drive innovation within their domain, such as Blackberry QNX's AVIC. Municipalities will need to be actively involved with any organization that is pursuing the development of CAVs to assist with its deployment and its future integration into urban environments however, a fragmented innovation network may make this challenging especially if public and private entities are limiting their level of cooperation to remain competitive. This includes cooperation between governments and the private sector, and between governments themselves. Good transparency and cooperation between the AV industry and governments will help drive innovation, make the region more competitive and support economic growth. Cooperation and coordination between municipalities themselves will hasten the deployment of CAVs into urban environments on a larger scale. For instance, if AVs have specific social and economic considerations or special requirements, a municipality that is not well informed of CAVs may be forced to integrate CAVs into their jurisdiction at a slower pace. This scenario would be problematic when looking at CAVs in Ontario holistically. As of now, CAVs are gaining more recognition from governments, but according to my research participant from OGRA, cooperation between municipalities in Ontario is limited at the moment.

7.5 Social Equity

While social equity is not exactly a challenge to overcome to help the deployment of CAVs, it is an important consideration once CAVs are deployed in cities. Transportation investments have a history of unequally servicing the public. As mentioned in Section 4, the planning of LRT routes are influenced economically and politically, which can infringe on establishing a socially sustainability transportation system. Investments in one particular geographical area, or within a particular aspect of transportation systems such as equipment or infrastructure, can be used as a city boosterism tool however, this can

lead to disinvestments elsewhere, particularly in places that need support. Of course, social equity impacts in transportation are intangible, as opposed to other impacts such as traffic flow and ridership, which makes it difficult to formulate and achieve social equity goals and policies. With numerous variables to consider, policy makers may consider using a multi-criteria decision making (MCDM) approach to better understand the impact of CAVs social equity (Manaugh 2015).

The true social impacts of CAVs are still unknown since CAVs have not been widely deployed in cities yet, at least not to the point where enough data on social equity can be collected for analysis however, transportation planners and governments will need to be cognizant of the social impact that CAVs may have. For example, using AVs in a MaaS program to address the FMLM problem in public transit may significantly increase the overall travel costs for people thus, making it more difficult for some people to travel.

7.6 Maximizing the Benefits and Potential of Connected and Autonomous Vehicles

A research participant from Durham Region described some of the challenges that Durham Region faces with regards to transportation. One of the challenges is incorporating technology into their transit system, such as cellular applications to help transit riders use Durham's transportation system. This poses a challenge for municipalities facing similar issues once CAVs are mass deployed and municipalities wish to incorporate CAVs into their transportation system. As mentioned in Section 6.3, the Town of Innisfil has partnered with ridesharing company, Uber, to assist with the FMLM problem, as well as assisting with transportation throughout the Town in general. Uber has a widely recognized and a user-friendly phone application to access its service, so by partnering with Uber, the Town of Innisfil did not have to invest a significant amount of resources into integrating that technology into their transportation system. If municipalities wish to purchase their own fleet of CAVs in the future and integrate it into their own transportation system to provide MaaS, municipalities may be challenged with the task of integrating the technology for public use. This is true for infrastructure as well. Barriers that prevent the integration of CAVs into public transit systems may include the installation and integration of technological infrastructure.

Another challenge that Durham Region is currently addressing is the movement of people to other jurisdictions outside of Durham for employment. As mentioned by my research participant from Durham Region, CAVs is just technology intended to solve problems, but it can also create new problems. My participant expressed concern that CAVs will make travelling easier thus, making it harder for Durham Region to retain people for employment. While there are other variables to consider aside from transportation when discussing economic growth, municipalities will need to determine how CAVs can be used as a tool to support the local and regional economy. The answer may lie with how CAVs are regulated and how it coexists with public transportation.

8. Conclusion

AVs are fast approaching and they have the ability to improve transportation systems and the quality of life for the people they serve however, there are a number of considerations regarding its integration into urban environments. The historical impact of transportation technologies on economic, social and spatial development is significant, which suggests that AVs will also change the way cities are managed and developed in the near and distant future. For example, the personal automobile facilitated suburban sprawl and the large-scale planning and development of highway infrastructure in the mid-late 20th century in North America. This created a planning path dependency that favoured the automobile that still persist today in certain ways – although governments now are prioritizing public transit and intensification to create more livable and sustainable cities. The economic, social and political impact of CAVs are fairly unknown given that CAVs have not been mass deployed into cities yet however, governments will need to prepare for CAVs by developing legislation, policies, plans and guidelines to manage CAVs in terms of its deployment and integration, but most importantly in a manner that ensures the future integrity of cities are upheld. For example, as discussed in Section 6.3, the Town of Innisfil, Ontario engaged in a public-private partnership between the Town and Uber Technologies to provide residents with subsidized on-demand transportation. This may create unpredictable outcomes such as the privatization of public transit, social inequity regarding transportation, or an increase in automobile dependency due to the partnership nourishing social values that favour automobiles.

As of now, we are starting to understand the impact that CAVs may have on cities and transportation systems. Time will reveal more definitive answers however; it is imperative that governments begin prioritizing CAVs today to ensure that its deployment and integration into their jurisdiction is synchronized with the goals and objectives that they wish to achieve.

8.1 Recommendations for Municipal Governments

- Create an internal working group dedicated to determine:
 - o How CAVs can be used as a tool for economic growth.
 - o How CAVs will impact public transportation, including how it can be integrated into existing transportation systems.
 - o The social and political implications of CAVs on cities and society.
 - o How CAVs can be used to support other goals and objectives the municipality wishes to achieve.
 - o The infrastructure needs to support CAVs, as well as its associated costs.
- Prioritize CAVs by integrate CAVs into existing plans such as OPs and TMPs.
- Establish partnerships with the automotive industry and with other municipalities, preferably through existing initiatives such as OGRA's MACAVO to minimize fragmentation.

8.2 Recommendations for Provincial Governments

- Continue to set provincial guidelines and legislation for CAVs.
- Consider the needs of the automotive industry to ensure legislation and guidelines do not hinder innovation and technological development.
- Continue to collaborate with automakers to help legislation evolve in conjunction with technological advancements, i.e. evolutionary testing.
- Continue to establish partnerships with the automotive industry and encourage the establishment of innovation initiatives in Ontario .
- Encourage membership and involvement between governments and between governments and the automotive industry.
- Provide funding for municipalities seeking to prepare for AVs.
- Designate more zones for CAV testing and allow more companies to test CAVs under *O. Reg. 306/15*.
- Determine the infrastructure needs of CAVs.

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