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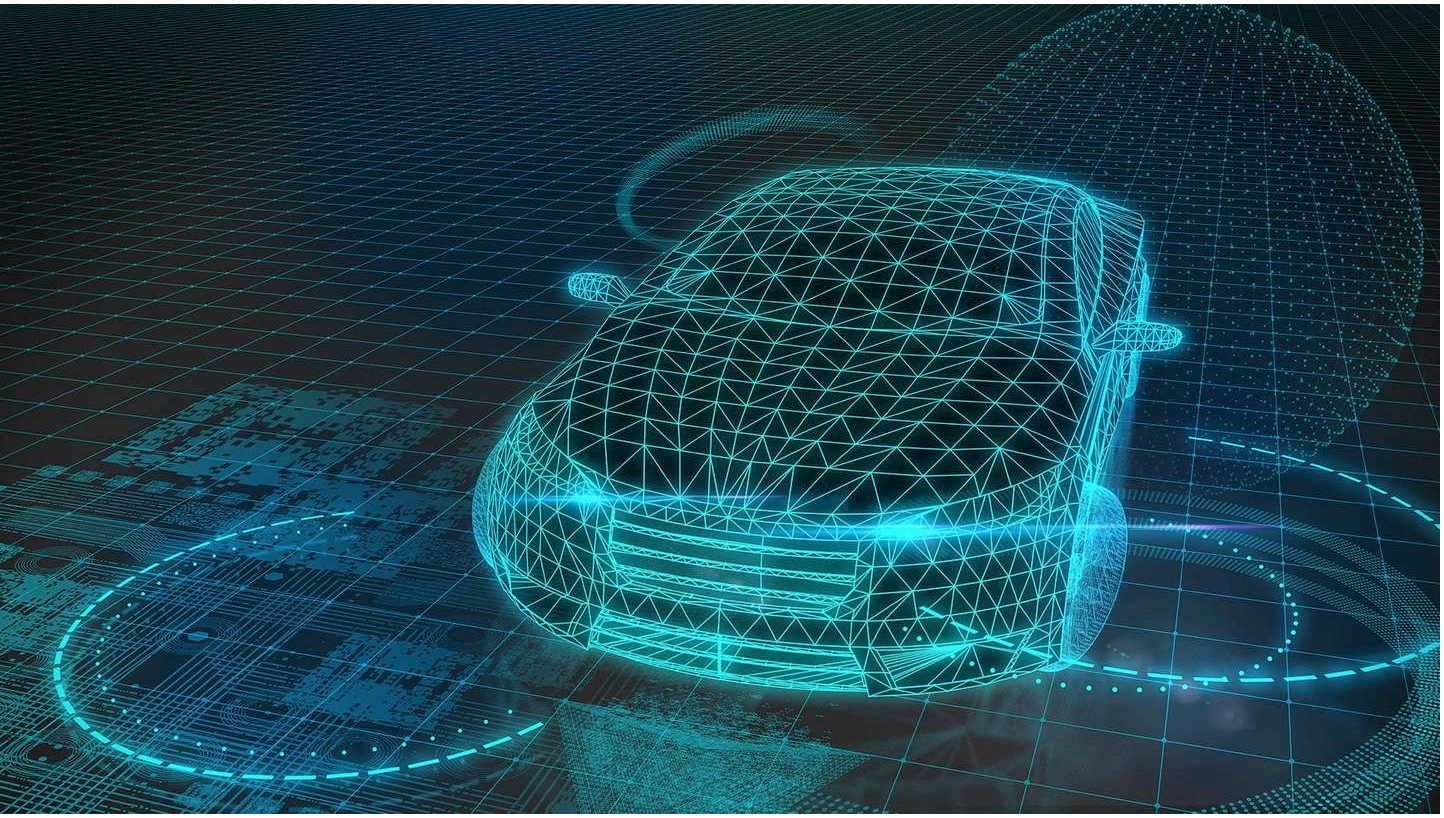

PICTURING AN AUTONOMOUS PICKERING

PREPARED FOR: IBI GROUP
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Letter of Submittal

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April 09, 2018

Mr. Vikram Hardatt
Transportation Planner
IBI Group
360 James Street North, Suite 200
Hamilton, ONL8L1H5

Dear Mr. Hardatt:

CROBY Consultants is pleased to submit a final copy of this report entitled *Picturing an Autonomous Pickering*. This report addresses each of the areas of research and discussion that were outlined in the RFP, and is the result of synthesizing an extensive literature review of papers, reports, case studies, and policies.

Should you have any questions regarding the report, do not hesitate to contact me at 519-897-1999 or by email at croby.consultants@gmail.com.

Sincerely,
CROBY Consultants

Lucas Braun
Project Manager

Acknowledgements

CROBY Consultants would like to thank IBI Group for the opportunity to work on this project, and for the engagement and feedback received throughout various stages of the process.

CROBY also expresses special appreciation to Faculty of the University of Waterloo's School of Planning for their support, without which this project could not have been accomplished, specifically:

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Executive Summary

This report ultimately provides policy recommendations for the City of Pickering to consider for inclusion in their upcoming Integrated Transportation Master Plan. A comprehensive literature review was used to inform the recommendations, and covers various aspects of autonomous vehicles: terminology and timelines, expected municipal implications, existing and proposed policy, and pilot projects. Additional research was conducted to understand the unique context of Pickering, and to establish an appropriate transportation vision for the City. Key findings and recommendations can be found below:

Overview of Autonomous Vehicles

- Autonomous vehicles are most commonly understood through the Society of Automotive Engineers' taxonomy that defines different "Levels" of automation, ranging from Level 0 (no automation) to Level 5 (fully autonomous at all times). Level 3 is the point where a driver can allow the vehicle to assume control at certain times.
- Level 2 vehicles are available for purchase today (e.g. Tesla autopilot), while Level 3 and Level 4 vehicles are being tested extensively on public roads. The commercial arrival of Levels 3 and 4 is expected to be within the next 5 - 10 years. Significant rates of adoption are not expect until 2030 optimistically, or 2050 conservatively.
- Connected vehicles are a distinctly different technology from autonomous vehicles. While autonomous vehicles are vehicles that are able to complete some or all of the act of driving independent of human control, connected vehicles are those that can wirelessly communicate with other technology, including other vehicles (V2V) and infrastructure (V2I). The two technologies can -- and are likely to -- be used together to complement each other.
- There are several variables that will dictate the effect that autonomous vehicles have on municipalities. Among the most important are the rate they are adopted, their dominant ownership model (i.e. whether private ownership continues, or if vehicle sharing becomes more prominent), and the fuel source most commonly used. It is recommended that the ideal scenario for Pickering is one of slow adoption to allow for a gradual evolution of policy and infrastructure, shared ownership to reduce congestion and emissions, and electrically powered vehicles to reduce the carbon footprint of transportation.

Municipal Implications Assuming a Shared Ownership Model

- As shared use of vehicles rises, the rate of single occupancy trips will fall, which in turn will lower the total amount of vehicle kilometers travelled and congestion. Congestion can be further reduced by the optimized acceleration and braking of autonomous vehicles syncing with connected traffic controllers to greatly increase the throughput of roads. A significant reduction in auto-based collisions and deaths is expected to result from automation because the vast majority of accidents are caused by human error.
- New infrastructure will likely be required to benefit from the efficiencies of connected vehicle technology, most notably the replacement of intersection control systems. Maintaining a detailed virtual map with information such as closures and speed limits may also be needed to allow autonomous vehicles to function properly. In addition, regular maintenance of signs and road markings will be needed to allow sensors to accurately interpret their environment. Large amounts of parking can be repurposed into smaller pick up/drop off areas in the case of parking lots, or expanded pedestrian right of way in the case of on-street parking.
- Resulting from a combination of reduced congestion, fewer vehicles operating on roads, and switching to electric power, emissions from personal travel are expected to significantly fall.
- Fully accessible autonomous vehicles can greatly increase mobility for groups unable to drive such as the elderly, disabled, children, and low income individuals. It is essential for this mobility to be affordably priced so that it accessible by all groups. One potential health risk is that the increased convenience of vehicle-based travel could reduce rates of walking and cycling, which would lead to higher obesity rates
- Economic benefits can be derived from reduced congestion and time in vehicles becoming more productive. There are particular industries -- largely those based around the use of private automobiles such as dealerships and insurance companies -- that are at risk of disruption, as well as many jobs that primarily involve driving.

New Mobility Case Studies

- Though there have been isolated cases of publically-driven AV testing in Canada, there has yet to be one completed on public roads. CityMobil2 is the leading example of using autonomous shuttles for public transportation, as took place in a variety of European cities, and documented lessons learned in terms of operations, safety, public perception, and next steps. It finds the best initial application of autonomous vehicles to be using them as a feeder system to higher order transit, which solves the first/last mile problem.
- Other municipalities in Ontario have run pilot partnerships with private companies to enhance their public transportation networks. Both partnerships were able to deliver transportation at a rate cheaper than that of a traditional bus service.

Transportation Vision

- The majority of laws and standards that will be needed to permit autonomous vehicles on Pickering's roads will come from federal and provincial levels of government. Key points of decision making for a municipal jurisdiction include: infrastructure investment/management, road design, public transit, parking and land use, and tolls on municipal roads.

Policy Analysis

- The majority of laws and standards that will be needed to permit autonomous vehicles on Pickering's roads will come from federal and provincial levels of government. Key points of decision making for a municipal jurisdiction include: infrastructure investment/management, road design, public transit, parking and land use, and tolls on municipal roads.
- No municipal policies on autonomous vehicles exist yet in the world. Within Canada, the cities of Toronto and Edmonton are leading the cause, and have commissioned reports containing policy recommendations to inform their decision making.

RECOMMENDATION TIMEFRAME

Recommendation	Timeframe				
	Quick Wins (1-2 Years)	Short Term (3-5 Years)	Mid Term (5-10 Years)	Long Term (10-15 Years)	Market Saturation (20+ Years)
Establish AV Working Group.					
Launch AV Shuttle Pilot.					
Create Financial Tools to Promote Share Vehicle Use.					
Start AV Education Program					
Inventorize signage and lane markings, revise maintenance schedule.					
Introduce AVs into DRT Service, as first/last mile connections or replacement for low performing routes.					
Launch EV charging station incentive program.					
Update road design guidelines to align with provincial standards. Test application of AV shared lanes.					
Create and maintain virtual map of city.					
Install first V2I traffic controllers.					
Reassess role of DRT given trends in AV costs and services.					
Update Land Use Policies to Reflect AVs					
Inventorize parking in city, and create conversion priority list. Develop tool to estimate total parking demand as a function of AV adoption.					
Introduce financial tools for promoting vehicle sharing, and adjust as necessary.					
Apply new road design standards and gradually reconfigure municipal roads.					
Launch policies and incentives to cause parking conversions.					
Upgrade additional intersections to V2I controllers.					

Table of Contents

Glossary

AV - Autonomous Vehicle
CV - Connected Vehicle
EV - Electric Vehicle
ITMP - Integrated Transportation Master Plan
TMP - Transportation Master Plan
V2V – Vehicle to Vehicle Communications
V2I – Vehicle to Infrastructure Communications
VKT - Vehicle Kilometers Travelled

Introduction

FIGURE 1. CITY OF PICKERING (SOURCE:TRCA, 2018)

The City of Pickering is in the process of drafting an Integrated Transportation Master Plan (ITMP) that will shape how transportation evolves in the City for several years. For a long-term plan such as an ITMP to be effective, it must consider the sheer amount of change that can occur across several years. In the case of transportation, changes to technology can be particularly pivotal, as has been observed through history as transportation modes have evolved from horse, to steam engine, to personal automobile. A new evolution in transportation is now looming: autonomous vehicles (AVs) are one of the most discussed issues in transportation forums today. The purpose of this report is to provide a comprehensive overview of what the implications of autonomous vehicles are for municipalities in general, what they mean for Pickering's context specifically, and finally to provide recommendations that will enhance Pickering's ITMP with resiliency to autonomous vehicles, and leverage them as a tool to achieve broader transportation goals.

Methodology

This project utilized extensive research in order to make effective policy recommendations for Pickering to manage AVs. There were two primary phases in the project, the first consisting of an extensive literature review, and the second synthesizing research findings into key insights and recommendations.

The research phase was divided amongst six targeted areas:

1. Best practices for transportation visions
2. The municipal implications of AVs
3. Pickering's context
4. Existing or proposed policies addressing AVs
5. Case Studies of AV pilot projects
6. AV Fundamentals

A variety of reference materials were used to obtain a full understanding of AVs; a combination of news articles, academic papers, professional reports, and government publications ensured that varying perspectives on an issue as contentious and complex as AVs were considered. A number of AV testing case studies were analyzed to supplement our research with real world results.

In the second phase, we synthesized our research with our analysis of the Pickering context. This includes a spotlight on thee city's transportation challenges and opportunities. This synthesis of contextualized research for Pickering formed the basis of our policy recommendations.

Part 1: Literature and Case Study Review

Autonomous Vehicle Primer

In the broadest sense, autonomous vehicles have existed for decades having been used in public transportation systems that rely on automation to operate fully separated rail metro systems in cities such as Copenhagen, Singapore and Vancouver. These automated rail systems are less complex than private vehicles operating on streets because their lateral movements are guided by rail technology and they only require longitudinal separation from other rail vehicles on the same line. However, with recent advancements in artificial intelligence, sensing and telemetry systems, and big data analytics, the automation of private vehicles has moved from the realm of science fiction to a looming reality.

Preparing for an urban future where AVs are prominent requires knowledge of the rapid industry advancements and the role that AVs will play in changing the way people and goods move. This section serves as a primer for key AV concepts, including levels of vehicle automation, the basics of how they work, the difference between autonomous and connected vehicles, and potential ownership models that drastically change the anticipated impacts of AVs.

What Are AVs?

Autonomous, automated, or driverless vehicles are common terms used to describe this emerging technology, with the former being the dominant term and thus used in this report. Generally, an AV is defined as a vehicle that can control itself (i.e., steering, accelerating, navigating, and braking) safely between destinations by monitoring the surrounding environment and avoid potential conflicts. The extent to which a vehicle can operate independently of human influence determines the degree to which it has been automated.

The Society of Automotive Engineers (SAE) (2014) has published a taxonomy that defines “Levels” of autonomy based on which elements of the “dynamic driving task” are performed by the system rather than the driver, as shown in Table 1. Levels 0 to 2 range from no automation to the vehicle being able to perform manoeuvres such as parallel

parking or lane centering. Many new models of personal automobiles offer these features already, meaning they are partially automated. At these lower levels, while the vehicle is able to independently control itself in some capacity, the driver still has full responsibility to control the vehicle and monitor traffic.

TABLE 1 LEVEL OF VEHICLE AUTOMATION (SAE, 2014)

Level of Automation	Control of Vehicle	Environment Monitoring	Emergency Response	Functions in all Driving Contexts?
0	Driver	Driver	Driver	No
1	Driver and System	Driver	Driver	No
2	Driver and System	Driver	Driver	No
3	System	System	Driver	No
4	System	System	System	No
5	System	System	System	Yes

Level 3 is a notable increase in capability from Level 2, because the system becomes the primary monitor of the driving environment and can control the vehicle with full independence, meaning that a driver could lift their hands and feet from the wheel and pedals and the system would assume control. This does not mean that a driver can disengage from driving however, because a Level 3 system requires immediate driver intervention in any situation where the vehicle cannot proceed with its existing (limited) logic. The driver's passive duty to intervene when needed is negated at Level 4, where for all appropriate "driving modes" (i.e. contexts), the vehicle can function fully independently and even react to emergency situations. To expand upon the idea of driving modes, a vehicle might operate independently on all road types except for ones in a dense urban core where traffic and pedestrian flows are known to be chaotic. A vehicle might operate consistently in clear or rainy conditions, but require human input in instances of snow. When there are no driving modes that the system cannot manage, full Level 5 vehicle automation has been reached. This taxonomy has been adopted by the United States Department of Transportation's National Highway Safety Traffic Act, and is generally used in Canadian papers, such as a report recently released by the Canadian Senate (Senate of Canada, 2018).

Level 5 automation marks the distinction of “autonomous” rather than “automated”, by entirely removing the need for human control or attention while driving. This distinction is critical, because many of the anticipated impacts of AVs will only be realized once vehicles are fully autonomous and passengers can use them without any expectation that might need to drive.

How Do AVs Work?

The operations of AVs can be simplified to three main phases: sense, plan, and act (Bagolee, 2016). Several sensors on the vehicle are used to detect lane configuration, signs, potential obstacles and competing road users. As the vehicle is driving, it will process these inputs and automatically adjust its steering, acceleration, and braking accordingly. The types of sensors found on current AV prototypes include radar, cameras, and LIDAR (light detection), which allow for close-to 360^0 monitoring of a vehicle. In addition, real-time positioning is enabled through GPS technologies to allow for route planning, as well as anticipating turns and ensuring correct road placement (Yousuf, 2016). Complex machine learning algorithms process large amounts of information from various sensor feeds and synthesize those feeds into a single mapping of immediate surroundings that constitutes the vehicle’s awareness. As the technology continues to progress, enhancements to AV systems and processes will define their capabilities and ultimately, their impact on the way people and goods are transported.

Connected or Autonomous?

Discussions of AVs will often mention connected vehicle (CV) technology as well. This creates confusion because these technologies are generally expected to be implemented together, but are distinct from each other; one does not necessarily imply the other. As described above, AV technology allows a vehicle to sense its environment and control itself accordingly. In contrast, CV technology allows a vehicle to wirelessly communicate with other connected technology, most notably other vehicles (“V2V”) and traffic infrastructure (“V2I”) (Anderson, Kalra, Stanley, & Sorensen, 2016). This comparison is shown in Figure 2. In the instances of a connected, but manually controlled car, the information exchanged between the vehicles could alert a driver signaling to change lanes that another car is in their blind spot, or that the car ahead has abruptly stopped. For example, a traffic light system with connected technology could dynamically adjust light times to the respective flows of traffic coming from each direction. It is important to

note that connected technologies would require significant decision-making to determine the desirable flows traffic, as well as how or if connected technology would accommodate other road users (e.g., cyclists, pedestrians).

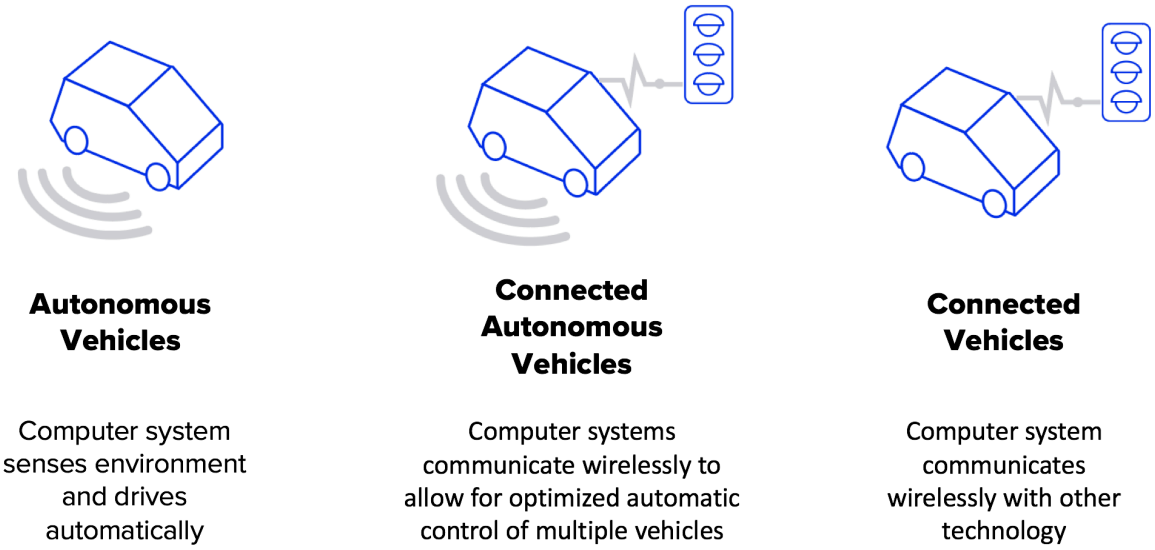

FIGURE 2 CONNECTED VERSUS AUTONOMOUS VEHICLES

This connectivity provides opportunities for increased safety and traffic efficiency in manual cars, but is limited by human reaction time and judgment of how to respond to sudden alerts. It is generally assumed that higher level AVs will have connected vehicle technology because the ability for these systems to directly communicate with each other would dramatically increase each car's awareness of its surroundings, and allow for collective optimization of traffic flows (Chong, 2016). If a highway had only connected AVs operating on it, traffic would hypothetically flow seamlessly because every lane change and merge would be broadcast to all nearby vehicles, which would shift their speed and make space as required.

Who Will Own Them?

The impact of AVs on various systems will vary immensely depending on the dominant ownership model. Individual ownership is the traditional model applied to private vehicles; each person owns their own car that they regularly use and typically sharing could occur if the vehicle owner puts their car into service to generate income, or be part

of a publicly or privately-owned fleet that optimizes the placement of several cars to respond to on-demand trip requests. The benefits of a shared ownership model include lower costs to travellers and decreased need for vehicle storage (i.e., parking).

In order to stress the importance of ownership models, consider two scenarios: In scenario 1, private ownership of cars has remained dominant as AVs became available, and the total proportion of vehicle ownership has actually increased because groups that previously could not drive (e.g. elderly or persons with disabilities) now own AVs. This equates to more cars on roads than ever before as ownership increases. Anyone that pays for parking would likely opt to send their AV home when out of use and summon it when they are ready to leave, which doubles the amount of driving being done despite no additional human trips being made. This scenario means more cars, and more vehicle kilometers traveled.

In scenario 2, a shared fleet of autonomous taxis serve a majority of the population that has forgone private car ownership. A premium can be paid to travel alone, but the pricing of the service encourages picking up multiple passengers who share similar origins and destinations. The fleet is optimized to maximize passengers per vehicle and minimize time spent empty by monitoring daily travel flows. This scenario means fewer cars, and fewer vehicle kilometers traveled.

Additional research is needed to determine the factors that will dictate which ownership model prevails over another (or if a split is more likely), but current research shows that in addition to cost (Bansal & Kockelman, 2017), cultures of technology enthusiasm and environmental preservation, as well as more dense neighbourhoods could encourage shared models of AV ownership (Lavieri et al., 2017). The model preferences of AV manufacturers will also be an important factor, given their control over product availability. It is important that policy-makers consider the impacts of various ownership models in order to promote a model that balances industry profits with environmental and social/health equity.

When Will They Come?

Several major AV testing initiatives are underway: Uber is testing driverless taxis in Pittsburgh and Phoenix; Waymo (formerly Google) has logged over 5 million miles on US

roads; and CityMobil2 saw autonomous shuttles in several European cities, to highlight a few. Assessing the current capability of these vehicles is difficult because updates generally come from commercial sources with incentive to promote progress towards full autonomy. The majority of testing completed so far has been in a Level 3 capacity where a technician is in the driver's seat and ready to assume control at all times. Recently, Waymo began testing Level 4 applications with no technician present in California (Kumparak, 2018).

Announcements from Ford, Waymo, Uber, and GM suggest the commercial arrival of highly automated vehicles will begin in 2019 and extend through the early 2020s. These dates reflect corporate goals that should be heard cautiously; companies have shareholders that undoubtedly want to see AVs commercially realized as soon as possible, meaning that these announcements reflect the 'best possible outcome' scenario for the technological advancements that have yet to be made. Despite industry promises of AVs being commercially available at the start of 2020s, several estimates of AV timelines that consider limiting factors such as cost, average lifespans of vehicles, and the gradual pace of policy to suggest that meaningful market penetration will not occur until at least a decade after commercialization (Fagnant & Kockelman, 2015; Litman, 2014; Milakis et al., 2017).

Even if the technology is made available in alignment with corporate timelines, regulations and laws must also change before consumers can begin using AVs. Current legislation only permits AVs to be tested in very specific situations: in relatively low risk environments with an actively monitoring driver present. Road laws are structured around the legal concept of a driver, which is challenged by autonomous driving. Given the breadth of public policy domains that relate to AVs, it is likely that the technology will outpace the legislation and standards needed to permit and regulate its operation.

Scenarios of AV Rollout

Given the variables discussed above, several different scenarios can be devised for AVs: for example, compare a scenario where by 2025 most people have forgone auto ownership to use shared ride sharing service, to one where by 2030 some wealthy individuals have privately purchased AVs that are unaffordable for the average person. The municipal implications for each scenario are drastically different because the

adoption rate and ownership model are flipped. From our literature review, we conclude that there are three key variables that determine how the effects of AVs will be felt in Pickering: the rate of AV adoption, the dominant ownership model of AVs, and the fuel source used to power them.

From the possible combination, **we highlight a scenario of slow adoption, shared ownership, and electrically-powered vehicles as preferable and likely for Pickering**. Slow adoption is assumed because the laws and standards needed for AVs are still completely absent in Canada, and is preferable because it allows more time for a gradual response to AVs. Shared ownership of AVs is much more sustainable, and promises to reduce congestion, lower travel costs, and reduce emissions. Emissions can be further reduced if AVs are electrically powered.

The remainder of this report is centered on this scenario to emphasize the importance of working towards realizing it over the alternatives. The municipal implications in the next section focus predominantly on what would happen in this scenario. The recommendations provided at the end of the report are either proactive in realizing this scenario, or reactive to the long term implications that it brings. Discussion of how the recommendations should change in the event of different scenarios can be found in the Appendix.

Municipal Implications

Transportation Implications

Mode Choice and Trip Behaviour

Widespread adoption of AVs raises questions in regards to how travel behaviour within Pickering would change. The Texas A&M Transportation Institute believes that individual AV ownership would be preferred over car sharing by a margin of 3 to 1 (Zmud et al., 2016). If

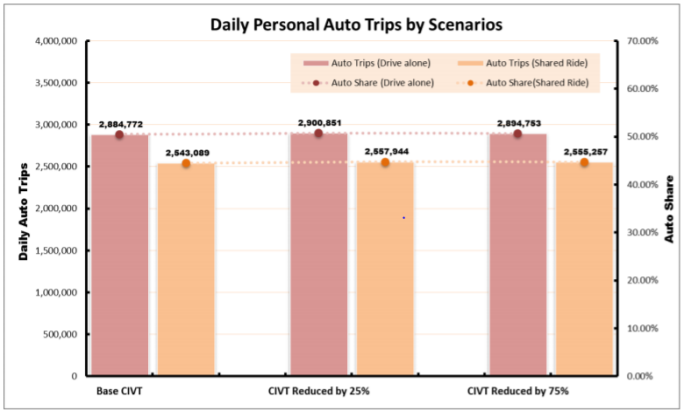

FIGURE 3. TOTAL TRANSIT TRIPS BY SCENARIO ILLUSTRATING THE POTENTIAL DECLINE IN TRANSIT MODE SHARE (ZMUD, SENER & WAGNER, 2016)

individual ownership was the adopted model it would be expected that mode share would change very little and if anything AV travel would increase in popularity. However, in a city model with shared AVs it would be expected that shared AV trips would take precedence over individual automotive trips.

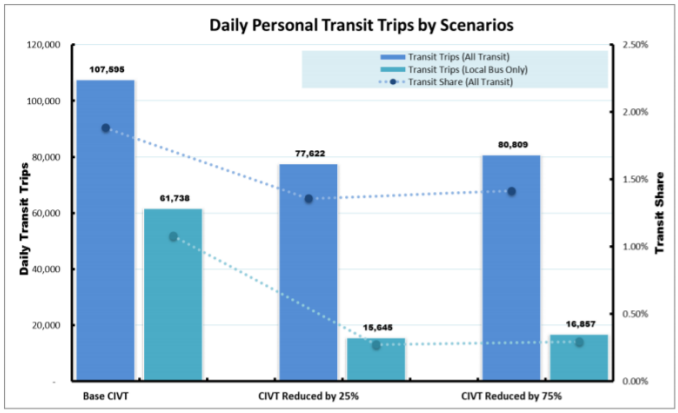

FIGURE 2. NUMBER OF TRIPS AV VERSUS TRADITIONAL VEHICLE IN A RIDE SHARING AND PRIVATE SCENARIO (ZMUD, SENER & WAGNER, 2016)

AVs may result in a reduced number of vehicles owned per household. In A&M's study 61% of respondents indicated that an AV would not change their current vehicle ownership, it would simply be an addition. 23% of respondents indicated that their number of vehicles owned would be reduced (Zmud et al., 2016).

The best determining factor of trip behaviour is vehicle kilometers traveled (VKT). There is speculation that AVs would reduce and increase VKT. In the same survey A&M found that 29% of respondents would maintain the same VKT (Zmud et al., 2016). While only 11% said there would be an increase (Zmud et al., 2016).

In 2010 the Capital Area Metropolitan Planning Organization (CAMPO) developed a travel-demand forecasting model for Austin, Texas. The model considered trip generation, distribution, mode choice and trip assignment. The model found that total daily VKT would increase slightly while the number of trips also increased (Zmud et al., 2016). Moreover, it indicated that individuals used less transit (Zmud et al., 2016). This would be reasonable to expect. As AVs became a more reliable option to public transit people would use it less and as the trips became more convenient people would use it more as well. In fact transit trips dropped from 107,595 to 77,662 in the model's study period. While in the same period auto trips increased by 30,000 (Zmud et al., 2016).

Congestion

The effects of AVs on congestion will be determined by the ultimate ownership scenario. In a private-ownership scenario, there is a risk that congestion levels will increase whereas in a shared-ownership scenario, congestion levels will likely decrease, however in the event that it increases, it will be regulated.

AV technology has the potential to alter trip behaviour altogether, however in a private-ownership scenario, there is speculation that the overall VKT could increase (Auld, Sokolov & Stephens, 2017). The reason for this is that at Level 5 autonomy of AVs, the burdens brought forth by being in the role of a driver is completely removed, thus may greatly increase the use of the transportation system. As such, externalities such as congestion may be negatively impacted. In a private-ownership scenario where every household can own multiple AVs, there could be an increase in the total number of vehicles on the roads especially during peak travel hours (Auld, Sokolov & Stephens, 2017).

In a shared-ownership scenario, the number of available vehicles will be finite. As a result, the number of vehicles on the road will be regulated. Although the following suggestion may be out of the jurisdiction of municipalities, an emphasis on transit and other rideshare opportunities is the optimal strategy to reduce VKT, ultimately reducing the number of vehicles on the roads and in turn, reducing congestion.

Safety

AV technology continues to emerge as the experimental phase is deployed in many cities, and safety implications are arguably one of the most important considerations. Though much of the onus for setting safety regulation and standards is within Federal and Provincial jurisdiction, municipalities will also face challenges and will need to address safety within traffic by-laws, safety plans, and other initiatives or programs so as to proactively prepare for and educate the public about the limitations of the technology; special emphasis will need to be placed on improved vehicle testing and the interaction between AVs and other modes like cyclists and pedestrians. The uncertainty and limitations of AV technology are widely acknowledged, as are the implications for liability and vehicle safety regulation on all roads.

Traffic Safety Implications and risks

Stakeholders attribute major causes of AV crashes to limiting factors including: programming errors and the limited sensor functionality in poor conditions, such as fog (Saripalli, 2017). AVs will have various implications for traffic safety that are debated among stakeholders. Potential risks for increased accident exposure include: software and hardware failures, system hacking, increased risk taking (offsetting behaviour or risk compensation due to less driver engagement and changes in reaction time), as well as platooning (AVs in dedicated lanes operating at close distances and at high speeds) (Litman, 2018; Dixit et al., 2016). Some argue that AVs are justified despite a predicted crash rate reduction of only 10%; others argue that the net benefits are low, especially depending on if the technology increases total VKT or in scenarios where the AVs operate in mixed traffic with human-driven cars (Litman, 2018). Others acknowledge that under a shared scenario, AVs can reduce crashes by taking high-risk drivers off the road (Litman, 2018).

AV Technology Benefits - Uncertainty

Arguments are made that AVs will reduce number of accidents due the reduction of human error due to the ability to communicate with the surrounding environment via smart technologies such as radar, lidar, and GPS (Lari, Douma, & Oniyah, 2015). Findings by the National Highway Traffic Safety Administration (NHSTA) show that about 93% to 99% of accidents are attributed to human error (Ni & Leung, 2014; Bagolee et al., 2017). The benefits derived from AVs range depending on the level of automation, although all levels are argued to reduce the number of collisions due to features like dynamic braking, blind spot assistance, and adaptive headlights (Ni & Leung, 2014). AVs are seen as a way to reduce the number of traffic accidents, as lower levels 1 and 2 automation have collision warning systems and lane departure warnings, while full automation, past level 4 autonomy, will likely reduce far more accidents given the added recognition technology (Ni & Leung, 2014).

However, the potential risks associated with AVs need to be addressed, especially under a scenario of rapid adoption wherein the presence of safety regulations and guidelines becomes crucial to prevent fatalities. Considerations must be made for implications such as operation of AVs in different seasonal conditions, lack of driver training, liability, and

full driver reliance on features such as autopilot which can reduce driver awareness and intervention in the wake of a potential collision. Recent fatalities between vehicles and pedestrians during vehicle testing demonstrate that AV technology has limitations in the ability to detect sudden changes in the surrounding environment (Saripalli, 2017). Cited reasons for a lag in safety regulations are the rapid nature of the technology outpacing the regulatory realm, as well as a lack of consensus among various stakeholders (Ni & Leung, 2014). This however has not prevented the creation of proposed standards, for example SAE's adaptive cruise control which aims to ensure AVs can respond to automobiles and other public road users (Ni & Leung, 2014). Ultimately, AV implementation is an important alternative to reduce and prevent vehicle-related accidents given the technology's potential to revolutionize how roads are used.

Infrastructure Implications

Vehicle-to-Infrastructure and Vehicle-to-Vehicle

Autonomous vehicles will impact how road infrastructure is built and may require a significant volume of reorganization to implement (Litman, 2017). While major manufacturers and early developers of AV technology are adamant that they may be implemented with minimal intervention, there will be no way around the need to install communicative infrastructure (Litman, 2017). Although early AVs may be able to operate without connected infrastructure (offline), long term implementation and advancement in AV technology would require this.

This is not something that is unfamiliar to the modern road. With the adoption of Automated Vehicle Location (AVL) technology on transit came a need to install various infrastructure elements such as omni-directional antennas, EMTRAC Priority Detectors and EVP detectors (Yuen, 2017). Communicative devices were installed on vehicles, at intersections and mounted on street light and power-poles. AV required technology would be similar in order to allow CV technology to transmit road sign, traffic signal information and internet connectivity to AVs (Godsmark, Kirk, & Flemming, 2015).

Traffic Control Technologies

AVs will require a number of adapted and new vehicle communication infrastructures. Building on the above vehicle-to-infrastructure technologies, the specific technical requirements pose a challenge. Broadband communications to relay information to and from AVs require a stable and high capacity broadband service provision. Germany's

Ministry of Transport and Digital Infrastructure outlines that they are dependent on a 50M Bit/s broadband service per antenna for AV connected infrastructure. Moreover, they found that 5G service would be the ideal situation to ensure smooth AV data provision. 5G mobile communications goes beyond the current 4G LTE service standard for cellular services.

Swarm intelligence through the cloud and digital audio broadcasting (DAB+) services, which is more efficient than analogue FM, can be leveraged to provide vehicles with real-time traffic information. High Precision digital maps are one of the more complex infrastructure challenges which must be addressed.

AV Mapping – Technology Behind the Car

A project lead by HERE Maps is looking into the ways AVs are managed on streets. Non-visible and visible navigation infrastructure is key to the successful implementation of AVs. HERE is developing three primary divisions of technology to achieve this.

1) High Definition Maps

High definition (HD) maps are needed not only to allow a vehicle to precisely position itself laterally and longitudinally, but also to allow it to maneuver more precisely. Traditional onboard sensors can currently see out to about 100 meters (Kent, 2015). This gives a car travelling at 80km/hr a sensing horizon of only three seconds (Kent, 2015). This becomes a concern when an AV is attempting to overtake another vehicle on a highway. The AV must be able to address the following questions (Kent, 2015):

- Is there another lane that it could move into?
- Are there legal restrictions preventing vehicle from overtaking or driving in the other lane?
- Is the lane wide enough?
- Is the stretch of road needed to complete the manoeuvre long enough so that the car can pass before the lane configuration changes?

The City of Pickering Roads are filled with buses and freight trucks as well as construction vehicles. If the argument is to address safety, there must be a way to increase this three second sensing horizon. If this cannot be done onboard it must be done using infrastructure.

2) Live Roads

There are dozens of mental calculations drivers make every second on the road. Live Roads would leverage connected vehicle technology to aggregate all sensor data from surrounding infrastructure and other vehicle sensors. This allows more accurate information of weather and road conditions to be sent to the AV network resulting in safer roads (Kent, 2015).

3) Humanizing the AV

Theoretically, an AV could operate safely at speeds much higher than what humans currently drive, but passengers may not feel relaxed or comfortable at these speeds. By analyzing long-term location-based driver behavior and understanding how humans drive, it is possible to make the autonomous driving experience more familiar and comfortable (Kent, 2015). HERE hopes to achieve this through the study of "speed profiles":

Modifying Existing Roads

Existing roads may be restriped in order to prioritise AV and non-AV lanes in certain areas of the City. This would be a low-cost option to the separation of AVs from regular traffic flows. Moreover, roundabouts have been found to be more efficient for AVs than standard stop lights indicating that roundabouts may become even more common than they already are (Godsmark, Kirk, & Flemming, 2015).

Signage will be the next change in the event of full AV adoption visible signage might be replaced with purely sensor signage allowing commuters to manage road warnings and restrictions. Until 100% adoption, signs will need to be accompanied by AV friendly signage (Litman, 2017). Moreover, there are generally three major options when it comes to AV existence on the roads. The first is that AVs integrate seamlessly with regular vehicles on shared lanes. The next is that they are completely separated from all other traffic and treated like a priority transportation network. The third is that they leverage off of HOV and bus lanes sharing road space with only those vehicles.

Parking

The most significant change in parking would be the significant decrease in parking need. With ride-sharing based around 2-to-10-minute wait times, the average vehicle occupancy during peak flows can increase from around 1.3 people to 2.9. With increased

ride-sharing at peak periods, more people can be moved by fewer vehicles (Godsmark, Kirk, & Flemming, 2015). The use of fully automated taxis and Ubers means that far less people will need to park their vehicles at their destination. This means largely reduced parking requirements for retail stores, commercial uses and recreational spaces. However, there will be an increased need for AV storage and (in the likelihood of EV adoption) charging facilities. There is a clear connection between AVs and electric vehicles (EVs) in which charging infrastructure will need to be amplified (Litman, 2017). This results in a chain-reaction calling for a significant increased in electric supply in the form of larger transformers and connection points.

With the reduced need for parking many parking now exhibit an increased demand for curbside or other drop off areas. This concern will be most easily addressed by adapting existing parking lots to dropoff and pickup zones. Larger parking lots such as the Pickering Town Center can follow the GO Transit drop off model. Smaller lots can follow kiss and ride patterns implemented by elementary and secondary schools.

1) GO Transit - Large Lots

GO Transit drop-off zones utilize a stacked automobile lineup in which drivers waiting to pick-up or drop off their passengers can park in and then proceed to drive out. The multiple lanes and drive-through lane allows for the constant movements of vehicles in order to avoid congestion (Figure 4). The current issue with the drop-off zones are drivers who wait in the lanes for extended periods of time. During peak hours this causes a pile up of vehicles as one lane is blocked. AVs would combat this issue. In a shared-adaptation approach the vehicles would not be waiting for extended periods on a specific person. In an individual-adaptation scenario the AVs could be programed to arrive within a certain time of needed pickup.

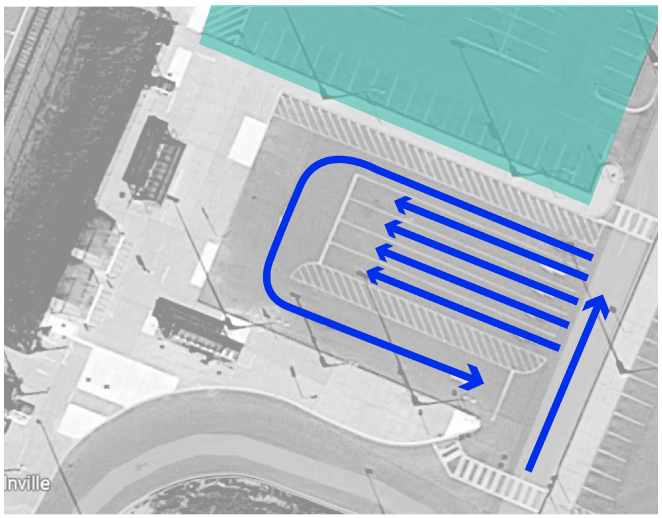

FIGURE 4. LARGE PARKING LOT (ADAPTED FROM GOOGLE MAPS, 2018A)

2) Kiss and Ride - Moderate Lots

Many elementary schools and secondary schools utilize kiss and ride zones. Essentially, they are the same as a pick-up and drop-off zone. The differentiation between these zones and the GO Transit model is that they are a single lane with a drive through lane to allow automobiles to come and go in between waiting for their riders (Figure 5). These can be adapted to smaller lots than the GO Transit model, but offer significantly less capacity. In this scenario AVs can be assigned to park in the center for the drop-off lanes to await riders when not in use.

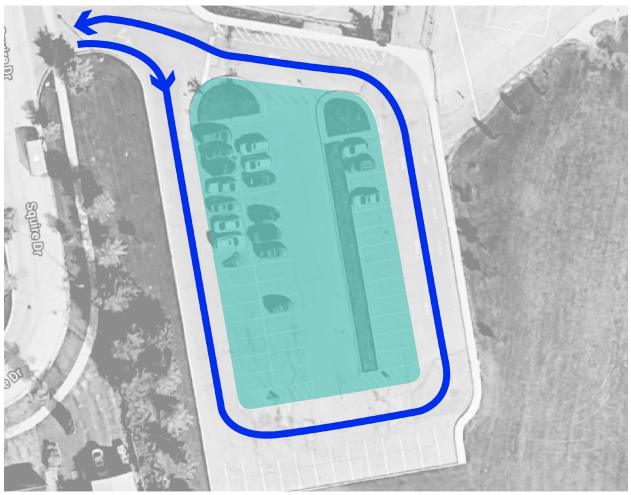

FIGURE 5. AUTONOMOUS VEHICLE PARKING AREA IN LIGHT BLUE (ADAPTED FROM GOOGLE MAPS, 2018B).

Environmental Implications

Table 2 summarizes an assessment of the potential AV Implications pertaining to the environment. Notably, these implications vary depending on shared versus individual ownership models. Although most benefits are derived from the former scenario.

TABLE 2 MUNICIPAL ENVIRONMENTAL IMPLICATIONS

Information was adapted from the following sources: Alessandrini, 2013; Clements & Kockelman, 2017; Miller & Heard, 2016; Smart Growth America, 2017; Anderson et al., 2016; Greenblatt & Shaheen, 2015).

" + "	" - "	Policy Implications
• Vehicle efficiency & operations (lightweighting, platooning, smart communication, etc.) • Reduced congestion (VKT) • Environmentally friendly fuel and power sources • Reduced parking infrastructure (new space for intensified development • Ride-sharing, on-demand shared mobility	• Increased speeds and increased commuting distances (increased VKT) • Unoccupied travel miles • Increased miles from underserved population • Long-distance, low density travel leading to sprawl	• Consider policies to minimize VKT and zero-occupancy AVs • Consider reducing parking infrastructure • Start discussions with community and stakeholders about the environmental impacts of shared versus individual AVs, invest in research initiatives/partnerships with major industries in Pickering (energy, environmental technologies, engineering) • Incorporate AVs in Corporate Energy Management Plan, utilize existing ROW infrastructure to accommodate AVs (e.g. plan for AV drop off zones) & promote intensification.

Traffic Congestion

Anderson et al (2016) and Greenblatt & Shaheen (2015) both discuss the ways in which AVs may impact traffic congestion, including total vehicle kilometers travelled (VKT) per capita, greater vehicle throughput on roads, and reducing traffic delays that come from collisions. The benefits could be seen in improved fuel economy, as AVs may be able to

promote smoother traffic patterns. Contrastingly, because AVs give drivers more leisure time within a vehicle, many may choose to reside in remote areas, furthering sprawl, and leading to an increase in VKT. AVs may also lead to new urban modal types, such as driverless taxi systems or carsharing, which could lead to lower VKT.

Accidents account for about 25% of all congestion delays, AVs provide an opportunity to reduce this percentage due to the suggested safety improvements and intelligence of the vehicles (Anderson et al., 2016). Similarly, Miller & Heard (2016) discuss the environmental impact of travel behaviour patterns, highlighting that while per-passenger kilometer greenhouse gas (GHG) emissions could decrease, total VKT could increase. Particular emphasis is placed on the latter, as automation means less driver interaction and more time to devote to other activities while in the vehicle; additionally, unoccupied travel miles may be problematic. As such, individual ownership could lead to increases in VKT and less reliance on public transportation, while shared AVs may reduce GHGs. Similarly, Anderson et al. (2016) note that VKT will likely be a factor of different cost components (e.g. operating costs, maintenance, parking, fuel, and opportunity cost), which would dictate travel patterns and behaviours.

Energy & Emissions

Anderson et al. (2016) discuss that the implications of AVs for energy and emissions will depend on the "fuel efficiency of AVs, the life-cycle emissions of fuel used to power AVs, and a total change in VKT resulting from the use of AVs" (p. 28).

Fuel economy improvements are likely to stem from level 1,2, or 3 adoption as driving is optimized for eco-driving (e.g. cruise control, smooth acceleration). Eco-driving can improve fuel economy by 4 to 10% (Anderson et al., 2016). Barcham (2014) also supports this, citing that eco-driving benefits can also be a function of lightweight and more aerodynamic vehicles, which decrease power and fuel requirements. The CCMTA (2016) notes that transportation accounts for about 23% of total GHGs in Canada; AVs have the potential to reduce this and promote fuel savings. More efficient vehicle design and road performance can contribute to reductions in energy use and subsequent emissions, and electric AVs could decrease gas emissions by 84-94% (CCMTA, 2016). Miller & Heard (2016) also note that technological attributes of AVs, such as light-weighting and platooning, will be favourable for fuel economy in terms of reduced traffic congestion and collisions. Greenblatt & Shaheen (2015) like other scholars, cite that alternative fuel

sources, such as hydrogen fuel cells or battery powered electric AVs, could yield improvements in air quality and reduce particulate matter and ozone depleting pollutants, or even a low-carbon electricity grid, which could reduce per-km GHG emissions by almost 90% (Greenblatt & Shaheen, 2015).

Land Use & Built Environment

Anderson et al. (2016) highlights that the value of a trip may increase with AVs, that is the opportunity cost associated with more leisure time in the vehicle due to the need for less driver interaction. This results in a decrease in cost, which may lead to more dispersed low density living. Contrastingly, AVs could promote intensification in urban areas, depending on parking supply and demand. AVs can reduce the need for parking infrastructure by the use of drop-off locations and the use of shared-mobility. Though this could free up space for infill development, a loss in parking could mean less revenue for municipalities (Anderson et al., 2016). Miller & Heard (2016) echo similar statements, citing that wide scale AV adoption will likely reduce parking infrastructure requirements, which may free-up land for other dense uses. Harrington & Schenck (2017) emphasize the importance of leveraging AV technology to have a positive impact on land use, as AVs can result in reduced parking needs and smaller land widths in urban areas, both of which can open space for new development.

AV Adoption Scenarios

Ross & Guhathakurta (2017) examined the environmental impacts of adoption scenarios: partial versus full automation and shared versus personal vehicle uses. The results demonstrated that full automation and single ownership would likely incur more energy consumption (increased travel speeds and new demand from new users), while despite an increase in VKT, a shared model may be able to reduce energy consumption depending on the percentage of shared trips. for example, Fagnant & Kockelman (2014) conducted an an agent based model scenario for shared AVs; their results demonstrated an overall benefit in terms of emissions reductions based on the pollutants evaluated. Greenblatt & Shaheen (2015) note that under a shared mobility regime, AVs have the potential to yield environmental benefits, particularly in shifting users towards shared mobility thereby reducing their reliance or need for private vehicles.

Social Implications

Table 3 summarizes an assessment of the potential AV Implications pertaining to society. Notably, these implications vary depending on shared versus individual ownership models. Although most benefits are derived from the former scenario.

TABLE 3 MUNICIPAL SOCIAL IMPLICATIONS

Information Adapted from the following sources: Alessandrini, 2013; Clements & Kockelman, 2017; Miller & Heard, 2016; Smart Growth America, 2017; Anderson et al., 2016; Greenblatt & Shaheen, 2015).		
" + "	" - "	Policy Implications
• Improve accessibility for those unable to drive • Shared mobility scenario would create an affordable mode of transportation • It is estimated that partial AV technology on all vehicles would reduce one-third of accidents, full AV could further reduce accidents	• Private ownership scenario would cater the wealthy and create an unaffordable product for most • Should AVs prioritize the safety of its passenger or the safety of others? • AVs could lead to increased physical inactivity	• Consider policies to encourage a more accessible and affordable scenario of AV implementation (e.g. plan infrastructure and routes to allow the public to maximize the use of AVs in both a private ownership and shared mobility scenarios) • Maintain a strong focus on transit oriented and active modes of transportation in major Pickering nodes

Accessibility

Cavoli et al. (2017) highlights that there is a strong potential for AVs to improve accessibility for a wide range of individuals including elder persons, individuals with disabilities, non-drivers, and those who live in areas that are not well connected to transport users. The adoption of AVs would increase a sense of independency and provide more flexibility in their lives. The 2018 Canadian Senate Report regarding AVs also mentions that the implementation of AVs offers social inclusion to those who have

never been able to drive and to those who are no longer able to drive. Furthermore, with the adoption of a new technology, there is an opportunity to incorporate universal design principles in AVs to offer a more equitable and accessible product for all.

Affordability

The question of affordability with AVs is reliant on the adoption method of the technology. Cavoli et al. (2017) suggests that in a private ownership of scenario, AVs will become a product that only serves the wealthy. On the other hand, shared mobility may benefit a broad range of users as the product may be even more affordable than a human-operated vehicle and private car ownership would decrease significantly. Anderson et al. (2016) suggests that successfully implementing AVs into the transit system is vital in creating a more affordable product.

Safety

With regards to the safety of AVs, Cavoli et al. (2017) describes an ethical issue at hand with the adoption of AVs. The dilemma is as to what extent should AVs prioritize the safety of their occupants at the cost of other individual's safety and if AV owners should be permitted to choose. Research suggests that in theory, the public would support a utilitarian AV where the passenger of the AV would be sacrificed for the greater good in the case of emergency. If this is the case, it would negatively impact the potential users/buyers of AVs as there is a sense that their lives could be at risk. Moreover, Anderson et al. (2017) suggests that AV technology has the potential to affect safety positively. The Insurance Institute for Highway Safety (IIHS) estimates that nearly a third of crashes could be prevented if all vehicles had some element of autonomy to it, including forward collision & lane departure warning systems, side view (blind spot) assistance, and adaptive headlights. When full automation is achieved, AVs may be able to avoid all crashes and emergencies, thus the ethical dilemma with regards to the safety of AV passengers will be moot.

Health

With regards to the potential health impact of AVs, Cavoli et al. (2017) suggests that AVs could lead to increased physical inactivity which could have detrimental health effects. As a result, there may be an increase in obesity rates as active modes of transportation would be discouraged with the convenience AVs would provide.

Economic Implications

Table 4 summarizes an assessment of the potential AV Implications pertaining to the economy. Notably, these implications vary depending on shared versus individual ownership models. Although most benefits are derived from the former scenario.

TABLE 4 MUNICIPAL ECONOMIC IMPLICATIONS

Information Adapted from the following sources: Alessandrini, 2013; Clements & Kockelman, 2017; Miller & Heard, 2016; Smart Growth America, 2017; Anderson et al., 2016; Greenblatt & Shaheen, 2015).		
" + "	" - "	Policy Implications
• Shared AVs are more economical as users pay for the use of the car (time or mileage) and decreases traffic congestions reducing collision costs. However, AVs affect many businesses and industries with shared fleets and vehicle sharing. This may threaten businesses such as traffic police, insurance, auto repairs, medical, and legal services.	• Individual ownership can be costly with burdens of maintenance, insurance, and other costs associated with ownership. Thus, car sharing has larger trends and is more economical.	• Consider policies that promote AV car-sharing or shared vehicles as this would be the most economical and long-term solution for Pickering.

Economic Benefits of AVs

Automated vehicles are also more economical than privately-owned vehicles as users would only pay for the actual use of the car (time or mileage) (Alessandrini et al., 2013). Secondly Automation and Inter-vehicle communications decreases traffic congestion. Additionally, connected autonomous vehicles (CAVs) will generate savings from productivity gains due to a reduction in collision costs and hands-free travel. CAVs will have major economic impacts and gain a large share of the automotive market, being $3,800/American per year or $1.2 trillion total (Clements & Kockelman, 2017)

Affected Industries/Businesses

CAVs may soon dominate the automotive industry (Clements & Kockelman, 2017). Once CAVs become affordable and reliable, it will generate significant economic ripple effects in many industries. The number of vehicle purchases per year may decline due the use of shared fleets or vehicle-sharing. Personal transport may shift to shared autonomous vehicle fleet use. This can threaten businesses for buses, taxis, and other form of group travel. Smarter automated vehicle operation result in fewer collisions with law-abiding vehicle. This will lower the demand for traffic police, insurance, auto repairs, medical, and legal services. CAVs may also impact infrastructure investment and land use as it leads to new methods for managing travel demands and repurposes some land such as off-street parking and curbside.

Trends in Using Vehicles

There are larger trends in car-sharing instead of car ownership as it frees burdens of car insurance, maintenance, and other costs that associate with ownership (Alessandrini et al., 2013). Surveys have shown that car-sharing membership has grown worldwide and in Europe it has increased from 212,000 (in 2006) to 552,000 (in 2010).

Case Studies

CityMobil2

CityMobil2 is a multi-stakeholder project that is coordinated by CTL and began in September 2012 and was completed in August 2016 (CityMobil2, n.d.). City Mobil2 sets pilot platforms for automated road transport systems implemented across several urban environments in Europe (Figure 6). Automated transport systems play a useful role in supplying good transport service (both collective and individual) in dispersed areas complementing main public transport network.

It has 45 partners from city authorities (including local partners), system suppliers, networking organisations, and the research community.

The first CityMobil project is classified in four categories of AVs (Alessandrini et al., 2013):

1. Personal Rapid Transit (PRT): automated individual transport systems that use 4-place vehicles and has networks with stops that carry passengers from the origin to the destination stop.
2. CyberCar (CC): transport system that can accommodate 4 to 20 passengers. Unlike the PRT, CC has different destinations and origins.
3. High Tech Bus (HTB): transport system based on automated road buses that accommodate more than 50 passengers. Various automated systems can be used as guidance, driver assistance, or for platooning and full automations.
4. Dual-Mode Vehicle (DMV): vehicle such as cars with ultra-low or zero emissions, have parking and driver assistance systems, and collision avoidance. This can be either operated driverless and fully automate or have a driver.

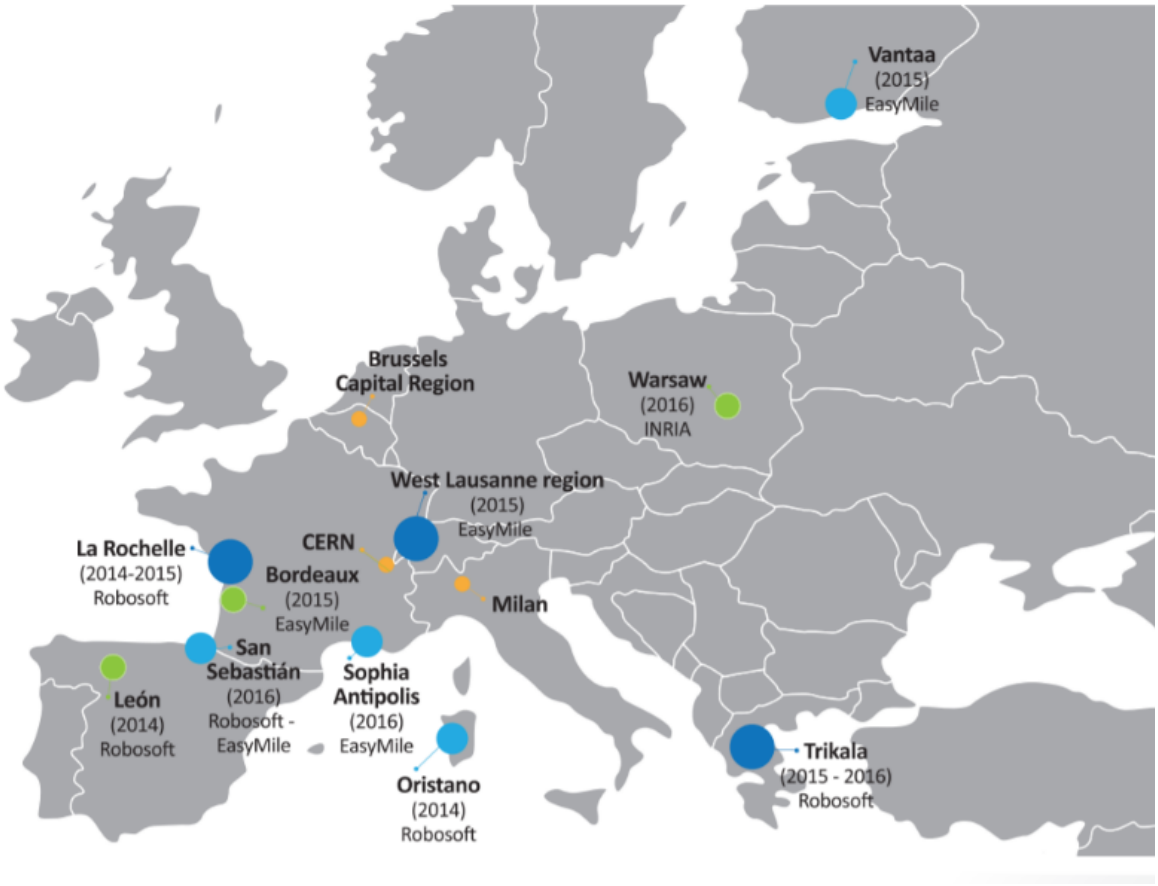

FIGURE 6 CITYMOBIL2 TEST LOCATIONS IN EUROPE (SOURCE: CITYMOBIL2, 2016).

Project Scope:

Commenced in 2012, CityMobil2 was intended to test AVs as a viable alternative to public transportation systems. Their majority of use was for “first” and “last” mile connections (CityMobil2, 2016). The project also considered the technical specifications and communication required. Three large scale trials were conducted in Milan, La Rochelle and the Commune of St-Sulpice. Trials began in 2014 and vehicles carried up to eight passengers.

Findings

Comprehension and Attitudes

Regarding safety, the effect of road markings was significant, with overall lower perceptions of safety in an environment where there were no road markings compared to an environment with road markings (CityMobil2, 2016). Concerning priority, where there were no road markings, about two thirds of participants believed that they had priority to cross the ARTS vehicle’s path. However, this went down to about one third in the presence of road markings. With regard to information about the behaviour and intention of the automated road vehicle, respondents reported greater importance of receiving information about the vehicle in the absence of road markings compared to when there are markings. There was no significant difference in terms of location, gender, or age categories on ratings of importance. Regarding preferences for type (modality) of information, there is a significant difference across the three locations between the ratings given to each information modality (i.e. visual text, visual lights, spoken words, and auditory signals) for all types of vehicle behaviour, irrespective of whether there are road markings.

Daily Trips

Daily trips increased as the self-driving car availability raised the flexibility and opportunity to combine daily travel schedules for different members of the same household. City-cores trips increased only when shared AVs were used due to an increased supply of capillary access (CityMobil2, 2016).

Average Journey Distance

This increased in the private AV context for all studied urban forms except for a small compact city. However in core-city scenarios, this increase was likely due to car sharing

scenarios where detours to pick up passengers increased travel distance (CityMobil2, 2016).

Vehicle Occupancy Rate

In the study occupancy rate for vehicles decreased due to increased empty trips in the suburban areas. This may be solved with a fleet approach over an individual ownership context. Fleet contexts increased occupancy between 10% and 30% (CityMobil2, 2016).

Lessons Learned from CityMobil2

What Can Cities Expect?

Early AV adoption will be used as feeder vehicles to main transportation networks. The study found that these AVs would be most effective on campuses, short distance services in specific locations (ex. events, specialised service routes), inside city centers, and on segregated lanes. Long term AVs are better used to manage peak-hour demand rather than provide a permanent replacement of traditional transportation methods (CityMobil2, 2016).

Steps to implement AVs

Ex-ante service dimensioning: integrated policies are recommended to push more people to use public transport, and therefore the policy goals must be defined prior regarding the available budget, quality of service and target modal share for public transport, which are the variables constraining the design of the network (CityMobil2, 2016). In this sense, AVs are not different from traditional public transport and require policies and measures that improve their performance with respect to the private car. A bus stuck in traffic will always be stuck in traffic even if it is automated.

Implementation Process: CityMobil2 was integrated within local public transport “ecosystems”. The roles were therefore divided between the project and the local participants (CityMobil2, 2016). The project experts defined the methodology and guidelines to be used by the cities in order to study and define the transportation function. Local transport operators had the role of providing the service through the operation of the system. AV manufacturers had the responsibility of installing the system, training the local operator’s staff and supporting the city with second level maintenance.

Urban Integration considers both the environment and the other vehicles. One must implement a new layer of regulatory rules when it comes to AVs and their interactions with other road users. One must also consider pedestrians and built form as speed increases so too does the risk of an accident. There are 3 levels of road infrastructure differentiation which include segregated, dedicated, and shared. Greater safety means lower AV speeds but efficiency means increased speeds and thus a balance must be determine. Safeguarding crossings is also an essential factor. In the case study, all crossings were secured with traffic lights. A better permanent infrastructure for crossings will need to be developed.

Canadian AV Pilots - Planned and Existing

FIGURE 7 LOCATION OVERVIEW OF THE EDMONTON AND STRATFORD AV PROJECTS.

Canadian AV testing is primarily focused on safety and improving AV responsiveness and reliability in all weather conditions (Kovacs, 2017). This is the largest challenge AV technology must overcome is snow in the Canadian context. This is the main focus of Active Aurora while Stratford focuses more on the real world application of AV sensors as they would apply day-to-day (Stantec, 2017). Table 6 summarizes the projects of Stratford's AVIN and Edmonton's Active Aurora. A general location of each project is highlighted above in Figure 7.

TABLE 5 SUMMARY OF CANADIAN AV PILOTS (KOVACS, 2017; THE CANADIAN PRESS, 2017;STANTEC, 2017)

Stratford - AVIN (Autonomous Vehicle Innovation Network) (Kovacs, 2017; The Canadian Press, 2017)		
Summary	Goals	Lessons Learned
AVIN allows researchers to test self-driving technology in real-life traffic scenarios. The AVIN includes a talent development program that supports internships and fellowships for recent graduates and students. In Ontario, there are more than 150 companies and organizations that are involved in the autonomous vehicle industry employing approximately 10,000 people. with a budget of $80 million	They are aiming to collaborate, develop, and commercialize Ontario based small and medium sized-enterprises, technology leaders, and automakers through a research and development partnership created within the network and demonstration zone.	AV testing in Pickering should occur in different climatic scenarios. It is important to test AVs in all four seasons and in different weather conditions as this can affect how AVs operate in these scenarios. Additionally, it is key to determine what must be done to the vehicles in order to cater for each scenario.
Edmonton - Active Aurora (Stantec, 2017)		
Summary	Goals	Lessons Learned

Active Aurora is a network of on-road test beds that provide a harsh winter climate in order to test Connected Vehicle systems, applications, technologies, and services for transit, active transportation, traffic, and goods movement. The project is also partnered with Stantec. This program provides real-world test zones for rural freeways, urban arterial roads, and urban expressways. Furthermore, these tests are combined with laboratory settings that cater towards various situations.	Currently in its first stage, the project is focused on "Improving Safety" by leveraging Connected Vehicle technology to reduce pedestrian collisions at signalized intersections.	Safety is a major component that should be analyzed when using and preparing an AV. For example, the technology used in AVs should be tested thoroughly using various scenarios that are specific to the area before they can be used by the public. In Pickering, it is key to determine where there is the most traffic and places with the most pedestrians. Additionally, the surrounding environments such as residential and institutional nodes should be taken into strong consideration.

Ridesharing Pilots

The Town of Milton, RideCo and Metrolinx Pilot

The Town of Milton partnered with RideCo and Metrolinx on a pilot revolving in getting to and from the GO Station which was completed in April 2016 (Cripps, 2015). Furthermore, Metrolinx is aiming to develop a concept that shows "first-mile/last-mile' options at transit stations that includes the GO network. In Milton, this will promote transit and roads will be used more efficiently. Additionally, they wanted to balance an individual user convenience with system efficiency. Further testing is required at various locations and contexts prior to considering a system-wide potential.

The options for customers included a $1.45 fee for common destination with other passengers or a $1.95 fee for door to door service (Cripps, 2015). The service is provided in the form of carpool to get to the GO Station. The average cost for the Town of Milton and Metrolinx would be $8.00 at a rate of $0.88/km (if an average distance of 7km is used since development surrounding the GO Station is limited to a 10km radius). Additionally, the average cost for customers would be $1.80 at a rate of $0.26/km (for an average distance of 7km). The highest ridership for this pilot was at 1700 trips with 40 rides per each peak period or 80 rides per week. The cost recovery rate was at 30% at the midway segment of the pilot which is better than Milton Transit at a rate of 24%.

The Town of Innisfil and Uber Pilot

The Town of Innisfil partnered with Uber on their first pilot. A study conducted by the town determined that the cost to hire and train drivers, to buy two buses, and install bus stops is $1 million (Pelley, 2017). The town set aside $175,000 for a period of six months. The customers from Uber can be picked up at a location of their choice but they would share the vehicle with other passengers and will receive a $5.00 discount to their total fare. However, there are also set destinations at a flat rate of $3.00 - $5.00 per trip. Table 7 shows sample destinations and origins including the fares of the pilot.

TABLE 6. SAMPLE DESTINATIONS FOR UBER PILOT BY FARE AND LOCATION (PELLEY, 2017)

Trip	Total Uber Fare	Resident Pays	Town Pays
Alcona to IRC	$9-12	$3	$6-9
Alcona to Barrie South GO	$15-20	$5	$10-15
Friday Harbour to Cookstown Tanger Outlet	$33-44	$28-29	$5
Cookstown to Town Hall	$22-29	$3	$19-26
Alcona Sobeys to Innisfil Beach Park	$7-9	$2-4	$5
Sandy Cove Acres to RVH	$26-34	$21-29	$5
Alcona to Hwy 400 carpool	$14-18	$5	$9-13

Lefroy to Barrie South GO	$19-25	$5	$14-20
Cookstown to Tanger Outlet	$9-12	$5-8	$5
Sandy Cove Acres to Alcona	$10-13	$5-8	$5

In particular to these sample origins to destination, the cost for both the town and the customer are at approximately $0.79 per kilometer. The number of trips made between the months of May to October in 2017 were approximately 2,475 (Ramsay, 2017).

Comparing both Pilots

When comparing both pilot projects, the Uber and Town of Innisfil partnership was more successful as they generated more trips per month at 2475 in comparison with Milton GO's which was at 1700 at the highest ridership month. Also, the Town of Milton only had one destination (the GO station) that serviced during peak service hours in the morning and afternoon whereas if it serviced all day, more trips would have been generated. However, the Town of Innisfil had multiple destinations which included a mall, beach, MTO carpool lots, a GO station, and downtown which increased the number of total trips. The Innisfil pilot also subsidized every Uber trip by $5.00, serving as an advantage in comparison to the Milton pilot.

Part 2: Pickering Context and AV Implementation

Pickering Context

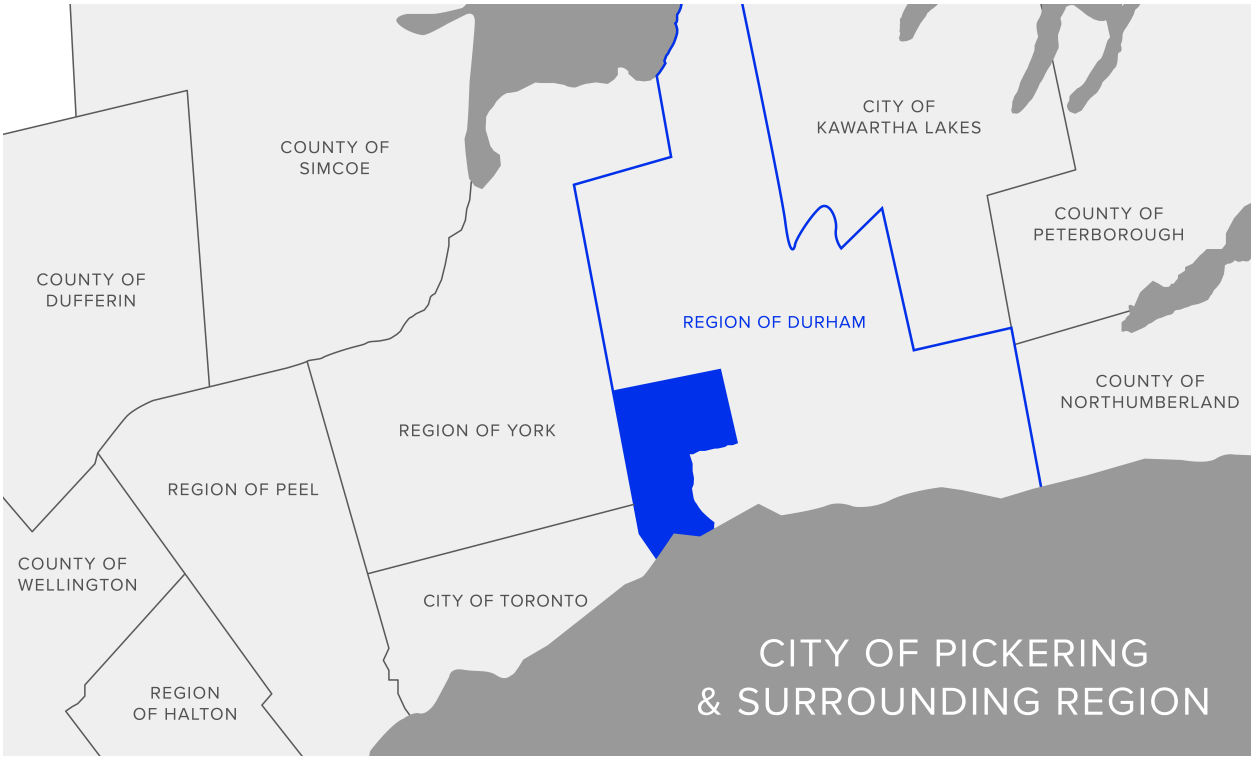

FIGURE 8 MAP OF THE CITY OF PICKERING & ITS SURROUNDING REGIONS.

Transportation Challenges

The City of Pickering is located East of Toronto in the Regional Municipality of Durham (Figure 8). As of 2016 Pickering maintained a population of 91,771 (City of Pickering, 2017). Pickering is largely comprised of a commuter demographic travelling West for work and recreation. Since 2001 the number of daily trips made by Durham residence had increased by 20%, with 80% of out-commuting conducted by individually owned cars (Durham Region, 2017a). Transit only comprises 8% of all trips in the area with other means of travel accounting for the remainder (Durham Region, 2017a). Pickering has a slightly higher share of transit compared to the rest of the region. Services provided by GO Transit and Durham Region Transit (DRT) have a 10% mode share instead of 8%

(Durham Region, 2017a). Car ownership in Durham is cited to be 1.8 vehicles per household with the average morning peak trip being 13.6km (Durham Region, 2017a).

Durham Region has three primary arterials to manage the large commuter volume. East-West Travel is managed by the Go Rail Network and Highways 401 and 407 (Durham Region, 2017a). Local trips are managed by Highway 2, Kingston Road, and provide a central arterial for GO Bus services and the crucial DRT Pulse rapid transit network. North and South Movement is primarily handled by Highway 412 and Highway 12 as they crucially connect the northern municipalities of Uxbridge, Port Perry, Cannington and Beaverton (Durham Region, 2017a). The City of Pickering's volume of traffic is directed onto Westney and Brock Road as well as the York/Pickering Townline. East-West traffic is absorbed by the 407, 401, Kingston Road, Taunton Road and Highway 7.

Pickering is one of the most challenging municipalities in Durham. This is largely because the City is predicted to experience the most dramatic population growth in Durham by 2031. Pickering's 90,000-person population is expected to hit 226,000 by 2031 while also predicted to maintain a similar mode share to what it has today (City of Pickering, 2017). The movement and flow of individuals will become the primary concern and with AVs most likely utilizing traditional road network this poses a serious problem (Durham Region, 2017a).

Currently Highway 401 in the Durham area often operates at capacity during peak periods. Moreover, on-road Bus Rapid Transit (BRT) lanes border the curbsides along Highway 2 restricting the number of traditional vehicles lanes (City of Pickering, 2017). Despite these new BRT lanes and the expected increased service by DRT the Region expects to see a ten-fold increase in auto trips. Some less notable concerns outlined in the Region's TMP include narrow 20m right-of-ways in Pickering Village and one-way streets (Durham Region, 2017a).

Further challenges for Pickering include contending with the proposed Pickering Airport and the accompanying transit and volume issues (City of Pickering, 2017). Coupled with AVs there may be some concern of an increased number of individuals wanting to move further away from central nodes to take advantage of AV mobility and more affordable land prices.

Innovation Corridor: Seaton

The Pickering Innovation Corridor will be located at the north edge of Seaton. It is bordered by Highway 7 to the north, Brock Road to the east and the 407 to the south. The Innovation Corridor offers access to five US border crossings in under a day's drive (City of Pickering, 2014). The corridor is also under an hour's drive away from Pearson International Airport. The corridor spans 800 acres. A residential to job creation ratio of 2:1 is targeted for Seaton which projects 70,000 residents and 35,000 jobs, 24,000 of these jobs will be in the corridor (City of Pickering, 2014).

Areas of Opportunity

AVs have great potential to influence how people and goods move in the region. First and last mile connections are one of the main areas in which AVs can be utilised in Pickering's transportation network. AVs can be leveraged to connect riders to major DRT and GO Transit hubs freeing up more rolling stock from the outlying local roads. Shared AVs can quickly become the norm in Pickering. As outlined in Durham's TMP AVs are expected to reduce congestion and provide a solution for low demand transit areas and act as feeder vehicles for rapid transit (Chan, Sadoway, Tzventarny, & Gulecoglu, 2017). This would address current DRT Specialised Service concerns as well as provide vital service to the more remote rural municipalities to the north.

Caution must be taken because in the absence of a shared-use model for AVs there is concern that the technology may result in skyrocketing VKT and many empty passenger vehicles driving on the roads (Chan, Sadoway, Tzventarny, & Gulecoglu, 2017). There is an opportunity here for the City to utilise policy incentives to reduce empty vehicles and encourage vehicle sharing. A charge could be placed on the number of deadhead kilometers a citizen's car completes annually (Chan, Sadoway, Tzventarny, & Gulecoglu, 2017).

There is also a need for policy development to consider the impacts and safety of AVs on other road users, particularly active transportation users and public transit. Future infrastructure will need to address the safe and efficient operation of AV technology. This technology is currently unclear but will need to be considered due to traditionally long planning and construction timelines in the GTA (Chan, Sadoway, Tzventarny, & Gulecoglu, 2017). Primarily, infrastructure needs should include requirements for connected vehicle

infrastructure (vehicle-to-infrastructure) and vehicle-to-vehicle (V2V) when constructing streets, highways and parking projects (Chan, Sadoway, Tzventarny, & Gulecoglu, 2017).

Transportation Vision

Approach

Precedence was gathered from existing vision statements to inform the creation of a transportation vision for Pickering. Key documents included the ITMP, Pickering and Durham's Official Plans, the Central Pickering Development Plan, the Durham Transit 5 Year Plan, as well as several Regional Transportation Master Plans (Durham, Waterloo, Edmonton) (Sources: City of Edmonton, 2009; City of Edmonton, 2017; City of Pickering, 2017; Durham Region Transit, 2016; Durham Region, 2017a&b; IBI Group, 2011; Metrolinx, 2017; Ministry of Municipal Affairs and Housing, 2006).

Key themes observed from the documents included: connectivity, accessibility, sustainability, multi-modality, innovation, efficiency, economic prosperity, and smart mobility. Based on these themes, the follow transportation vision has been established for the City of Pickering:

Vision 2040

Vision 2040 is based on leveraging innovative technologies to create an interconnected, safe, accessible, and efficient multi-modal transportation network that promotes smart mobility, environmental sustainability, economic prosperity, and social equity, for present and future generations.

The City of Pickering's Integrated Transportation Master Plan (ITMP) will be an essential tool for creating a network that is both adaptive and responsive to the needs of the locale, and for advancing the following goals of Vision 2040:

- An integrated multimodal network that prioritizes viable sustainable mode choices including walking, cycling, and transit
- Safe, affordable, and accessible travel options for both local and regional trips
- Bolstering economic growth, enhancing community quality of life, and preserving ecological resources

These goals will be achieved by:

- Identifying key nodes and travel corridors

- Promoting and supporting Transit-Oriented Development on greenfield sites along major corridors
- Making informed infrastructure investment decisions to provide multimodal links along these corridors
- Enhancing transportation infrastructure with new technologies to increase efficiency, safety and convenience

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Regulatory Frameworks & Existing Policy

Regulatory Framework

There is minimal existing policy and laws on AVs in Canada. There is no Federal Policy on AVs as of yet, however Table 7 provides an overview of the potential responsibilities of different levels of government regarding AV implementation adapted from CCMTA, (2016: 5) and other sources with some modifications (Sources: CCMTA, 2016; Government of Canada, 2016&2018; Isaac, n.d.; Queen's Printer for Ontario 2016, 2017, 2018 a&b; City of Pickering, 2017a&b, 2018; Durham Region, 2017c):

TABLE 7 REGULATORY FRAMEWORKS, ROLES AND RESPONSIBILITIES

Level of Governm ent	Existing Laws/Regulations	Regulatory Role
Federal	• The Canadian Transportation Act • The Canadian Transportation Accident Investigation and Safety Board Act • Canadian Environmental Protection Act	• Establish national AV policy and regulatory framework • Ensure vehicle manufacturers comply with safety standards • Collaborate with other nations to harmonize implementation strategies and adopt similar standards • Govern emissions and energy requirements • Privacy/data sharing, and cyber security • Raise public awareness

Provincial	• Highway Safety Act, under which key regulations pertinent to AVs has been adopted, namely O Reg 306/15 Pilot Project for Automated Vehicles. • Other notable regulations and laws include O Reg 413/05 Vehicle Weights and Dimensions For Safe Productive Infrastructure Friendly Vehicles; Public Transportation and Highway Improvement Act	• Create regulatory framework that allows for effective and appropriate testing and deployment of AVs • Ensure compliance with Federal regulatory documents • Govern safety, registration, and licensing • Plan, develop, and budget for AV infrastructure • Increase public awareness
Municipal	• The Municipal Act • Pickering: Official Plan, Zoning By-law, Traffic and Parking By-law, Pickering City Centre Design Guidelines • Durham Region: Regional Official Plan, By-Laws (Traffic, etc.)	• Seek opportunities to integrate AVs with public transportation • Municipal AV enforcement and regulatory adherence • Update municipal road design and traffic guidelines • Plan for new development (e.g. on lands previously required for parking) and access along roads • Plan for new ways to raise revenues to finance and manage AV supportive infrastructure • Prepare for changes to transit (operations, labour, fee structures) • Increase public awareness

Discussion

Pickering would have limited jurisdictional control over AV implementation. The majority of the regulatory provisions would come from the Federal and Provincial levels of government. As such, coordination and collaboration between all three levels of government will be essential for effective implementation of AVs in Pickering. Additionally, in specific reference to vehicle testing and pilot studies, Pickering and other levels of government can collaborate and learn from best practice AV policy implementation in other countries around the world. However, as evident in the table,

these regulatory limitations should not hinder Pickering from proactively planning for AVs, as this would be a step towards Pickering becoming a model city for AV policy development and could also encourage greater discussion in Federal and Provincial policy realms. Given the regulatory limitations, planning instruments, such as the Official Plan and the Integrated Transportation Master Plan (ITMP), will likely be the primary tools for planning for an autonomous future.

Existing AV Policies

In this section, existing AV policy documents from the Canadian and American context will be summarized. The main policy recommendations pertaining to AV implementation in Pickering will be identified from the Canadian Senate - Standing Committee Report and the US Department of Transportation (DOT) - Federal Automated Vehicles Policy , outlined in Table 8).

TABLE 8. EXISTING FEDERAL & PROVINCIAL POLICY RECOMMENDATIONS PRECEDENT (SENATE OF CANADA, 2018;DOT,2016).

Author / Document	Summary	AV Policy Recommendations
The Senate (Canada) Standing Committee Report	The Canadian Senate Report recommends how each level of government and various government agencies should tackle the challenge of regulating the deployment of AVs in a proactive manner. The report has a total of 16 recommendations which address how all three levels of government should address various issues relating to AV implementation such as vehicle safety, cybersecurity, privacy, infrastructure, and public transit.	Since majority of the AV policy recommendations from this report are for the Federal and Provincial levels, only the recommendations pertaining to municipalities are included below: Collaboration should occur through the Canadian Council of Motor Transport Administrators between Transport Canada and provincial, territorial, and municipal governments to create provincial policy to guide the use of AVs and CVs on public roads.

	This document highlights the safety, environmental, human & social, and economic benefits that the implementation AVs would provide. Contrastingly, the report identifies potential challenges with AVs such as job loss, privacy, cybersecurity, urban sprawl, and infrastructure – all of which are addressed in the recommendations.	Efforts should be made by Transport Canada to gather relevant stakeholders to create an AV/CV framework. Stakeholders should include, but not be limited to, governments, the automotive industry, and the public. Key issues to be addressed include vehicle safety and data privacy.
	The Senate Report also outlines the existing initiatives within Canada as well as existing initiatives in other jurisdictions. The document highlights that the Province of Ontario is the only province that has introduced AV regulation with Ontario Regulation 306/15 which creates a 10 year pilot program which permits the testing of AVs.	Continuous collaboration between Employment and Social Development Canada and provinces/territories is imperative to support individuals that may be impacted by the potential labour market disruptions that may occur with AV implementation. “Public Safety Canada and the Communications Security Establishment work closely with the provinces and territories to develop cybersecurity training materials and programs to improve public understanding of cybersecurity issues.” (p.14)

US Department of Transportation (DOT) Federal Automated Vehicles Policy	The DOT policy document discusses the potential implementation of Highly Autonomous Vehicles (HAVs) in regards to vehicle performance, state policy, current regulatory tools, and new tools and authorities. The document discusses vehicle requirements, design, development, and testing (permitted in many states). Current federal law in the US does not present a barrier to HAVs being offered for sale so long as the manufacturers comply with certifications and design parameters (based on SAE levels of autonomy), but will still be subject to National Highway Traffic Safety Administration (NHTSA) safety inspections (including data recording and sharing, crash tests, human-machine interface, etc.).	States should remain responsible for vehicle licensing and registration. Public roads are under Federal and State jurisdiction, so HAVs must comply to both regulatory frameworks, including the allowance of DOT to regulate the performance of HAVs. Also discussed is the need for driver training and education, as well as testing. The document clearly states the divisions in responsibility between Federal and State authorities, of which wouldn't change in the case of HAVs. Federal authorities will be responsible for enforcing compliance, developing guidance for manufacturers to follow, while the state is responsible for licensing, registration, enacting traffic laws, conducting safety inspections, and regulating insurance and liability.

	The document also considers new tools that the Agency or transport agencies can use to support safe HAV implementation; particular emphasis is placed on the role of research to guide creation of new tools, pre-market assurance tools (e.g. testing), pre-market approval authority, hybrid certification/approval process, ability to cease and desist, and so on.	NHTSA will continue to regulate the safety of vehicles themselves, including the ability to recall unsafe vehicles. NHTSA has four tools to address new technologies: "letters of interpretation, exemptions from existing standards, amendments or creation of new standards, and addressing defects that may pose a risk" (p.48).

Discussion

Overall, there is key emphasis shared responsibility, collaboration, safety, and enforcement in the aforementioned policy recommendations. An analysis on the applicability of these documents to municipal policy will be based primarily on the Canadian context, with particular emphasis on the Canadian Senate report and two municipal reports which will be expanded upon in the next section.

Precedent Municipal Policy Recommendations

In this section, AV policy recommendations from the City of Edmonton and City of Toronto will be reviewed as an existing example for AV policy recommendations for Pickering (Table 9). Municipal policies applicable to the City of Pickering will be highlighted from these documents.

TABLE 9 MUNICIPAL POLICY RECOMMENDATION PRECEDENT

Summary	AV Policy Recommendations
Antonio Loro Consulting Inc. *Planning for AVs in Edmonton Report*	
This report summarizes the consultant's work for the consideration of AV technologies in the City of Edmonton. The report highlights the significant impacts of AVs on aspects such as land use and travel patterns based on various adoption scenarios and levels of automation. The report also provides detailed recommendations for AV implementation – although these are not broken down according to federal, provincial, or municipal responsibility, inferences can be made about how much leverage a municipality would have over certain recommendations and further how these recommendations can be translated into policy.	Some preliminary policy recommendations are provided in the report (Antonio Loro Consulting Inc, 2016): • Public transit: consider protected laneways for AVs, implement bus platooning technology, provide frequent service in low-density areas, consider drop-off/pick up zones, promote use of automated buses or taxis • Walking / cycling: deploy and price AVs strategically to ensure a fair modal-share, provide pedestrian & cycling infrastructure & links to AV zones or transit station areas

	• Roads: consider dedicated ROWs, consider pricing mechanisms to reduce VKT and congestion, consider platooning technology to increase throughput on roads • Parking: price parking strategically to discourage demand (under level 2 or 3 automation); convert park-and-rides • Land use: utilize pricing mechanisms to discourage dispersed development, support development near higher order transit or rapid transit lines, redevelop parking land to support intensification, reuse on-street parking for pedestrian or cycling facilities or green space • Pilot studies: encourage studies for level 1, 2, and 4 automation on a small scale (e.g. business parks, campuses, etc.) • Community/stakeholder engagement: create working groups, educate the public, conduct research on priority areas (e.g. modelling land use impacts)
David Ticoll *Driving Changes: Automated Vehicles in Toronto Discussion Paper*	
This report highlights research analysis and findings based on a project led by the University of Toronto's Transportation Research Institute (UTRI).	Some preliminary AV implementation elements that should be regulated at the municipal level (Ticoll, 2015): • Transition from taxis and other ride service companies to autonomous mobility services • Parking: AV implementation may lead to a decline in vehicle ownership in the long run, many on- and off-road parking may disappear

The document identifies potential AV policy and planning recommendations to inform strategic municipal decision-making pertinent to AV adoption and implementation in the City of Toronto. Key topics of discussion include implications, opportunities and challenges for city policy development, such as transportation and urban design policy, as well as items to consider based on city policy objectives (e.g. complete streets, congestion reduction, equity, increase transit use, etc.).	• Accident reporting: data may assist in improving AV technology with a focus on safety • AVs in winter: accommodate for snow conditions • Data policy: data is useful for municipalities from a transportation, planning, management and enforcement standpoint, however there may be concerns about data ownership, privacy and security. • Urban design policy considerations: complete streets, multi modal integration • Consider funding sources (e.g public private partnerships) • Community/stakeholder engagement: develop working groups, facilitate discussions within the community • Plan for pilot studies - consider a potential network for AV routes or AV rapid transit • Research: partner with or consider stakeholders to conduct research for trial AV implementation

Discussion

The Edmonton and Toronto studies were the most prominent reports that provided comprehensive AV policy recommendations that would be most applicable at the municipal scale. The findings of these studies provide several precedent policy recommendations that can inform or guide AV policy development in the City of Pickering. The discussion papers highlight some policy areas in which Pickering should focus on as precedent for creating AV policies.

Other Municipal Policy Considerations

Ridesharing Policies

Another important area of consideration for policy and regulation is ridesharing as the implementation of AVs will create greater opportunity for this. Currently, ridesharing services operate in regulatory grey areas. Existing by-laws, regulations, and other policies were not created with the consideration of this peer-to-peer service. As a result, municipalities must be proactive in regulating this phenomenon by reviewing and revising by-laws. Some steps that can be taken in regulating ridesharing is to clarify by-laws, create exemptions within by-laws, and support ridesharing by promoting ridesharing initiatives. Public policy goals must be kept in mind when creating regulations for ridesharing as potential negative impacts include more cars on the road, more competition with traditional businesses, and greater risks to citizens who participate as sharers (Guelph, 2017).

Right of Way Visualizations

The current roads in Pickering are categorized into local, collector, and arterial, illustrated in Figure 9. What is outlined in red are the highways that are not in municipal jurisdiction. For those that are, we've created conceptual cross sections demonstrating potential AV impacts on roads with different functions.

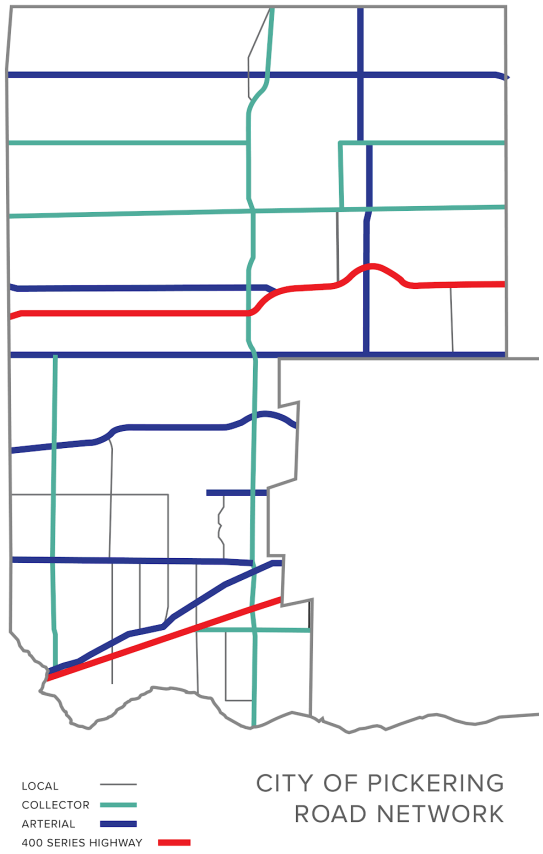

FIGURE 9 MAP OF THE CITY OF PICKERING'S ROAD NETWORK

Shared Lane Designation

We propose a new road designation that marks a lane shared by autonomous and regular vehicles. Autonomous vehicles will be required to use this lane, and regular vehicles will have the right to share this lane based on driver preference. The shared lane designation addresses public concerns about the safety of AV vehicle integration

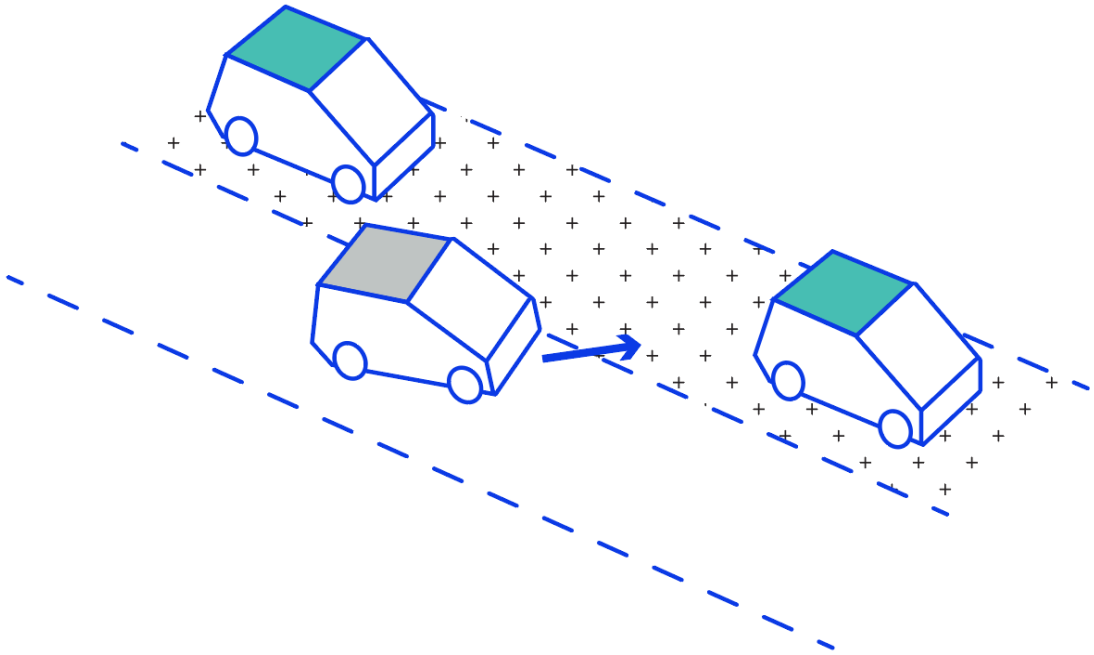

FIGURE 10 ILLUSTRATION OF A SHARED AV LANE

into the road network. In addition to facilitating transitions in low adoption model, the shared lane method will also be applicable in the high adoption scenario. Shared lanes will be necessary on roads where the as-of-right road width cannot facilitate a dedicated AV lane. Shared AV lanes will be distinguished by colour painting.

Dedicated AV Lane

In the high adoption scenario, sufficient market share of autonomous vehicles will generate demand for the designation of dedicated AV lanes. Autonomous vehicles require narrower lane widths, which will increase right-of-way re-allocation opportunities.

Low Adoption Street Design Objective

In designing Pickering's roads for the low saturation scenario, the main objective is to integrate AV into the existing road network prioritizing safety of all modes of transportation. The aim is to accommodate for the gradual public acceptance of autonomous vehicles, while investing in infrastructure to prepare for increased adoption in the future.

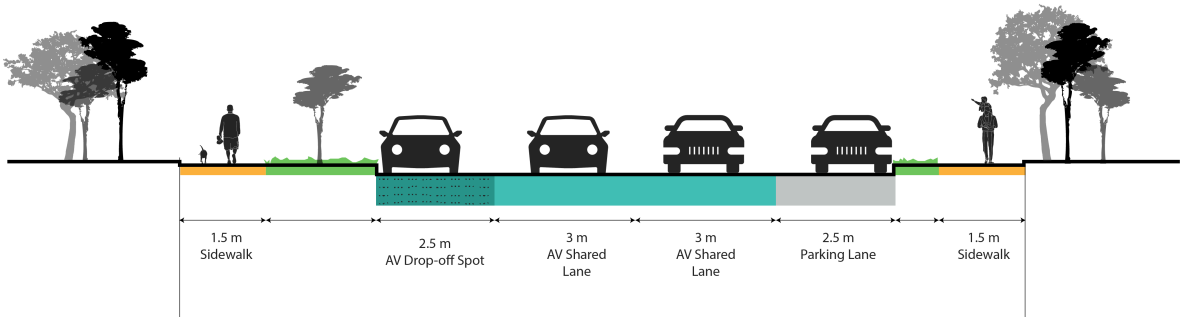

FIGURE 11 LOCAL STREET CROSS SECTION UNDER LOW SCENARIO

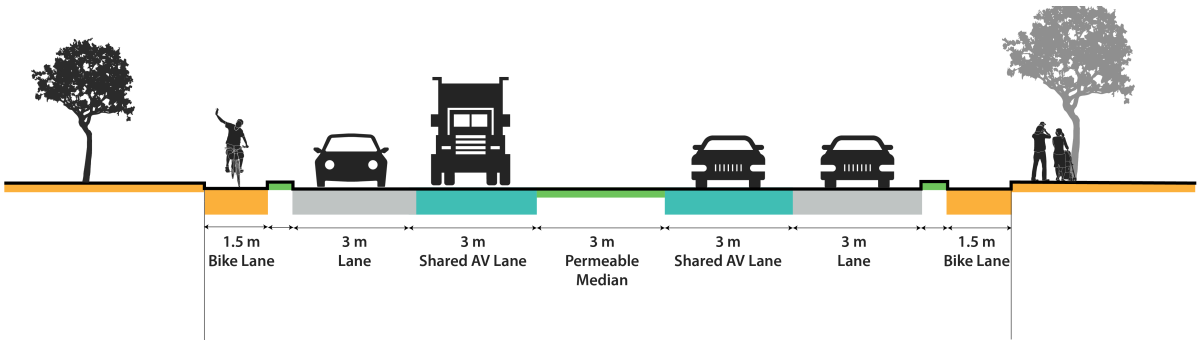

FIGURE 12 COLLECTOR STREET CROSS SECTION UNDER LOW SCENARIO

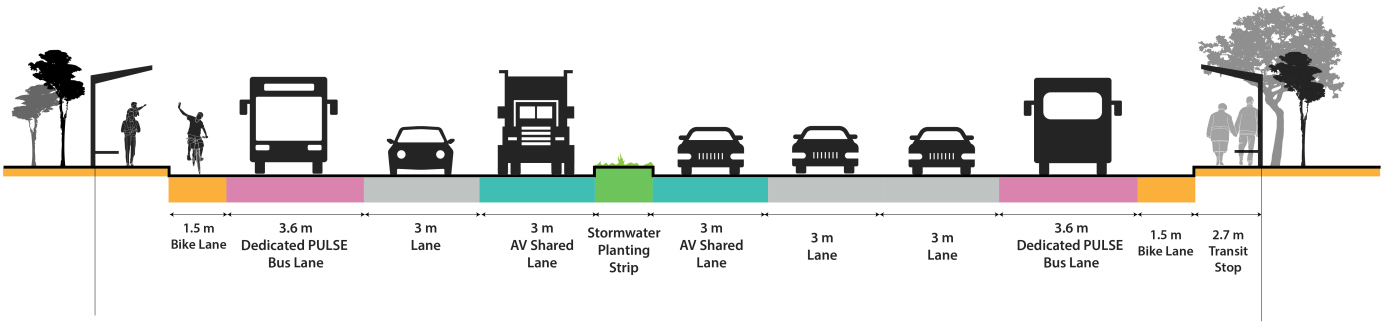

FIGURE 13 ARTERIAL STREET CROSS SECTION UNDER LOW SCENARIO

High Adoption Street Design Objective

The high adoption scenario is developed under the assumption that autonomous vehicles will make up the majority of auto vehicles on the roads. In this scenario, AVs have changed how we use our streets. Here, the design objective is to redesign our streetscape in order to maximize the potential benefits of autonomous driving by greatly reallocating road spaces.

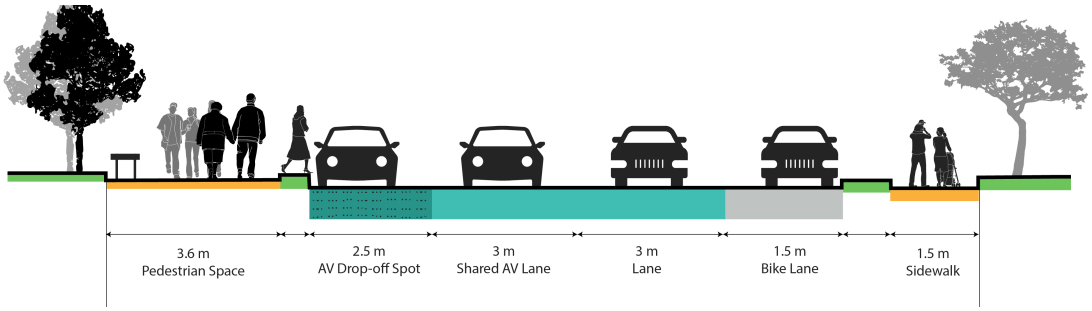

FIGURE 14 LOCAL STREET CROSS SECTION UNDER HIGH SCENARIO

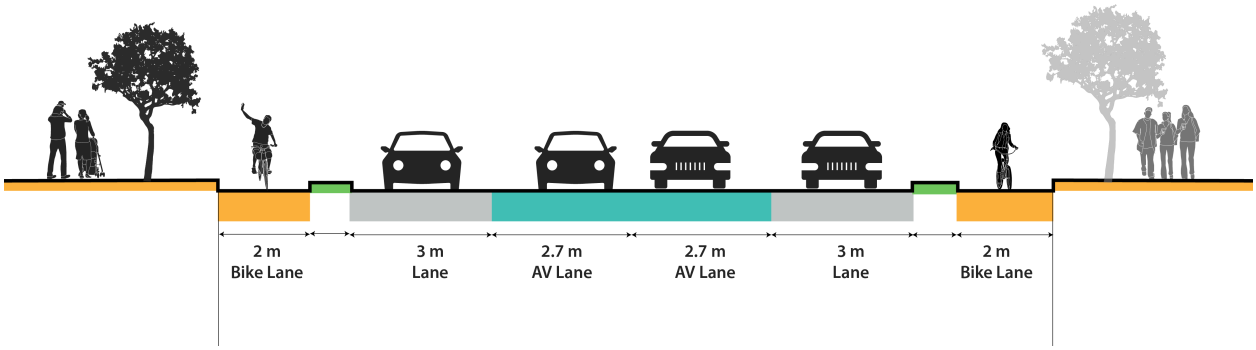

FIGURE 15 COLLECTOR STREET CROSS SECTION UNDER HIGH SCENARIO

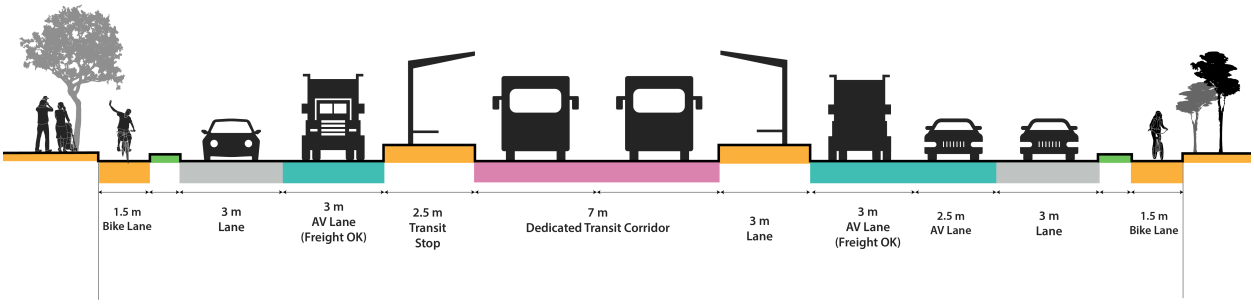

FIGURE 16 ARTERIAL STREET CROSS SECTION UNDER HIGH SCENARIO

Design for Complete Streets

Preparing the City of Pickering's streets for autonomous vehicles, regardless of adoption level, offers the opportunity to enhance the streetscape for other road users such as pedestrians and cyclists. A common element among both adoption scenarios is widened, separated bike lanes to encourage cycling behaviour. In addition, to support the City's stormwater management initiative, we recommend implementing stormwater planting strips and permeable medians. On roads where dedicated AV lanes are proposed, lane width can be narrowed, thus freeing up right-of-way space for the pedestrian realm.

Challenges and Solutions

There are a number of challenges and opportunities associated with AV implementation in the City of Pickering (Table 10). The ideas presented are a culmination of synthesizing the research findings and subsequent analysis presented throughout the report.

TABLE 10. AV CHALLENGES AND SOLUTIONS

Challenges	Solutions
Transportation	
• AVs may decrease the mode share of more sustainable forms of transportation in favour of single occupant vehicles • An increase in VKT may require more road capacity • Convenience of AVs may encourage long commutes and increase rate of non-resident workers travelling to work • Possible danger arising from a transition period where human drivers share the road with AVs	• Ensure that transit and active transportation are competitive through usage charges to single occupancy vehicles • Keep other modes competitive, and install connected vehicle infrastructure that increases road throughput • Introduce distance-based usage charges
• An unproductive parking surplus is caused by the switch to pick-up/drop-off trips • Delivering first-last mile transit options in low-density suburbs	• Introduce AV-only lanes initially to segregate different driving styles; provide education on how to safely interact with AVs. • Identify parking spaces that can be converted in part into a drop off area, and otherwise into new more productive land uses. • Use AV shuttles as a cheaper alternative to full-sized buses
Municipal Policies and Administration	

• Difficulty in managing an unprecedented project in a public setting • Ensuring that policies do not lead to unintended consequences (e.g. increased VKT, sprawl etc.) • Coordination with upper levels of government and associated agencies to ensure policies align (Durham Region, Provincial, Federal) • Depending on ownership model, fiscal constraints (e.g. how will funds be raised to pay for AV implementation?) • Ensuring that policy directions will actually result in behavioural change (e.g. increase public transport ridership)	• Partner with firms or agencies that have expertise with AV pilots to lead the project; establish a working group to monitor trends. • Identify all potential consequences and manage the risks associated. Keep policies adaptable. • Establish and maintain regular dialogue with upper levels of government • Create a financial task force, consider Public-Private Partnerships • Educate and engage the public on AV implementation; creating incentives to encourage the use of AV ride services
• Ensuring policies are adaptable to address uncertainty (rate of adoption, progression of technology) • Ensuring by-laws are adaptable to AV implications (e.g. pedestrian and traffic safety, ROW urban design, curbside and parking infrastructure, etc.)	• Maintain a keen eye on the development of AV technology • AV safety programs or initiatives; public engagement that encourages driver education and training; coordination between City departments (engineering, urban design, transportation, planning, etc.)
Urban Design and Land Use	
• Determining the best road configurations for AVs, and balancing right of way for AVs with that of other modes in a way that promotes sustainable transportation • Sprawl is exacerbated as the perceived cost of driving gets lower.	• Wait until more robust guidelines on AV road design have been established by the province before changing roads. • Alter land use policies to push developers towards intensification; use tolls to disincentivize long commutes.

Sustainability	
• A switch to ride-hailing models of mobility make transportation inaccessible to those without internet access or aptitude. • Loss of driving jobs causes economic disruption. • Increased use of vehicle-based travel in favour of active transportation raises obesity levels.	• Maintain a municipal service that provides education on AV services and can arrange rides for individuals that need assistance. • Provide education and retraining resources to improve individuals' resilience. • Invest in active transportation infrastructure (e.g. separated bike lanes or widened sidewalks).

More broadly, a fundamental challenge for any Canadian municipality to influence AVs is that the fundamental laws and standards that will govern what they can and cannot do will be established by the provincial and federal governments. Given a relatively slow response from these levels of government, Pickering (and other municipalities) should engage with them to stress the need for federal and provincial guidelines. The recommendations made in the next section are made in accordance with matters that are municipal jurisdiction and therefore actionable for Pickering.

Recommendations

Through considering the municipal implications of AVs, the case studies and policy recommendations referenced, and the goals of Vision 2040, a list of recommendations has been created to maximize the benefits of AVs, and minimize their potential consequences. Recommendations are divided into three main categories: administrative, where the function of municipal staff will change; programs, where a new initiative is led by Pickering to direct change, and infrastructure investment. A brief discussion of each recommendation is provided below, while a summary of all key items ordered by time is shown in Table 11.

TABLE 11 - SUMMARY OF RECOMMENDATIONS

	Timeframe				
Recommendation	Quick Wins (1-2 Years)	Short Term (3-5 Years)	Mid Term (5-10 Years)	Long Term (10-15 Years)	Market Saturation (20+ Years)
Establish AV Working Group.					
Launch AV Shuttle Pilot.					
Create Financial Tools to Promote Share Vehicle Use.					
Start AV Education Program					
Inventorize signage and lane markings, revise maintenance schedule.					
Introduce AVs into DRT Service, as first/last mile connections or replacement for low performing routes.					
Launch EV charging station incentive program.					
Update road design guidelines to align with provincial standards. Test application of AV shared lanes.					
Create and maintain virtual map of city.					
Install first V2I traffic controllers.					
Reassess role of DRT given trends in AV costs and services.					

Update Land Use Policies to Reflect AVs					
Inventorize parking in city, and create conversion priority list. Develop tool to estimate total parking demand as a function of AV adoption.					
Introduce financial tools for promoting vehicle sharing, and adjust as necessary.					
Apply new road design standards and gradually reconfigure municipal roads.					
Launch policies and incentives to cause parking conversions.					
Upgrade additional intersections to V2I controllers.					

Administrative

Establish AV Working Group

Establishing a working group of city staff to lead efforts relating to AVs is the most logical first step in managing the onset of the technology. The City of Toronto offers a precedent for this type of group, bringing together 21 representatives from different city divisions to ensure that roundtable discussions of AVs have the comprehensive perspective of all municipal stakeholders.

Key duties of the working group would include:

- Staying current with AV news and trends, and corresponding with potential private partners.
- Serving as a point of contact for inquiries regarding AVs, and initiatives involving them.
- Sharing findings with memos that keep knowledge of staff, politicians, and the public current.
- Identifying key stakeholders for each recommendation and working with them to establish a timeline, action plan, and budget.

Immediate establishment of an AV working group is beneficial regardless of the rate of adoption or ownership model that come to be.

Collaborate with Durham Region Transit to Evolve Public Transit

It is not yet clear how the role of public transit will change as AVs arrive. It may be that privatized on-demand vehicle sharing allows for a cost-effective provision of mobility that supersedes the need for conventional public transit, or it may be that integrating AV technology into a public transit system can enhance its competitive edge against driving.

The results of the AV shuttle pilot recommended under Programs would be a first step in understanding how public transit might change. If the pilot is successful, it may be a viable way to increase service coverage in neighbourhoods away from transit routes, or entirely replace a low ridership bus route that is heavily subsidized. This project should be completed within the next 5 years.

Key Tasks Include:

- Partner with a private AV shuttle company.
- Use data from DRT to determine a suitable route for the pilot.
- Establish an evaluation tool that can identify when part or all of a bus route can be more cost-effectively delivered by an AV.

As AVs mature, it will become clearer how public transit's role is changing. New discussions with DRT will be needed to adjust plans, and possibly the fundamental role of public transportation.

Potential questions include:

- Are full-sized autonomous buses a cheaper way to deliver service by lowering labour costs?
- Does on-demand ride sharing provide sustainable transportation more cost-effectively than DRT? Can be considered route by route, as the answer will be contextual.
- If privatized ride sharing services become dominant, how can it be ensured that no groups are marginalized by ability or income?
- If DRT assumes control of AV technology, what knowledge and skill gaps must be filled? Does a partnership where DRT sets metrics for a private company to meet make more sense?

Expand Efforts to Maintain Signs and Road Markings

Autonomous vehicles use a variety of different inputs to properly understand their surroundings, including which lane they are in, accounting for nearby users of the road, and determining which rules currently apply to them. One of these inputs is a camera feed of signs and road markings, which is critical to the AV driving predictably and safely.

Key Tasks Include:

- Keeping a full inventory of all signs and lane markings up to date. If the industry trend is that this information is more reliably accessed through a standardized virtual map, create and maintain this map.
- Determining if AVs can automatically notify city staff when markings/signs are absent, unclear, etc.

Review Land Use Policies

How AVs will influence land use demands and supplies is also unclear. It may be that the convenience of being able to sleep, work, or relax while 'driving' encourages commuters to buy cheap land in areas that are low density and far from the city core. To offset this potential for sprawl is the opportunity to greatly reduce the need for parking (as expanded on in the Infrastructure recommendations), and redevelop that land to increase density. Zoning can be combined with financial incentives such as reduced development charges to encourage developers to intensify instead of sprawl.

Key Tasks Include:

- Review the official plan and zoning by-law to make changes that consider AVs. Examples of changes include reducing minimum parking requirements, and redesignation of parking lots suited for redevelopment.
- If deemed necessary based trends in the development industry, financially penalize sprawling development, and incentivize infill development, especially in former parking lots.

Programs

Launch AV Shuttle Pilot

A pilot project of operating an AV shuttle would serve a variety of useful functions. It tests how well AV technology functions on Pickering's roads, introduces the technology to the public gradually to increase awareness and gather feedback, and demonstrates how well AVs can synergize with DRT routes. Contacting a representative from CityMobil2 is highly recommended to consult their expertise in starting and running an AV shuttle service.

Key Tasks Include:

- Consult CityMobil2 for guidance through the pilot.
- Partner with an AV shuttle manufacturer to provide vehicles, and operational expertise.
- Collaborate with DRT to determine suitable locations.
- Record public feedback, operational statistics, and costs/revenues to allow for a cost-benefit analysis of AV shuttles against bus service.

Begin AV Education Program

The purpose of this program would be to communicate to the public that AVs are becoming a reality, that they might cause large disruption (such as job loss), and how the City of Pickering plans to use AVs to achieve certain goals. This messaging can mitigate disruption by preparing those at risk of job loss to begin retraining, communicate how to safely share the roads with AVs, and stress why sharing vehicles is beneficial for the city.

Key Tasks Include:

- Update the municipal website to include a section on AVs that contains general information, municipal initiatives, and contact information for appropriate staff.
- Host public information centres to educate, and receive public feedback.
- Use provincial and federal guidance to deliver messaging on safely using (or traveling near) AVs.

Subsidize EV Charging Infrastructure

A key component to making electric vehicle usage more attractive is adequate provision of charging stations throughout a city. Pickering can achieve this by creating incentives

for developers to building charging stations on their sites, such as a rebate program, or as a negotiating tool for minor variance or zoning bylaw amendment applications. Installing these stations on busy municipally owned sites such as libraries or city hall can serve as leading by example.

Key Tasks Include:

- Consult with the Ministry of Energy to see what provincial programs are already in place to encourage the use of EVs.
- Install municipally-owned charging stations.
- Trial rebates and land use tools, to determine which is the most effective in generating private participation.

Explore Financial Tools to Push Shared Mobility

The risk of sprawl, more single or zero occupancy trips, longer commute trips all come from the convenience of AVs. Even if shared mobility options are made readily available, individuals may still opt for the privacy and convenience of a private trip. To counteract this, financial tools such as pay-by-distance road tolls, or commuter taxes could be used to discourage unsustainable trips. Strategies for this are still evolving, so a peer review of best practices as AVs become more prevalent is recommended.

Key Tasks Include:

- Review best practices of other municipalities that use financial triggers to influence travel behaviour.
- Introduce the trigger if congestion and sprawl are found to worsen, then monitor how they change from of adjusting rates to find the ideal price.

Infrastructure

Repurposing Parking

The shift to ride sharing and the pick-up/drop-off model of mobility should drastically reduce the need for parking in the City of Pickering. Conversions can only happen when the adoption rate of AVs is significant enough that the demand of parking is notably lower. Once this point is reached, parking lots can be converted into pick-up/drop-off areas that occupy considerably less space. Leading up to that point of saturation, an

inventory of parking lots, on-street parking, and parking garages can be made that streamlines the process of conversion. The changes to land use policies discussed above are a necessary complement to this conversion.

Key Tasks Include:

- Create inventory of all parking within the city and create a priority list of areas most suited for conversion.
- Develop a tool that can estimate the amount of parking needed in the city as AV adoption rises.
- Begin conversions once AV adoption is high enough.

Road Redesign

The repurposing of on-street parking, as well as the prediction that AVs can operate in narrower road lanes creates opportunity to redesign roads to be friendlier for pedestrians and cyclists. Specifications will have to first come from the province; once those are released, Pickering can draft new road design guidelines. Similar to repurposing parking, the changes to road configurations can only be as large as the adoption rate of AVs. A shared lane for AVs and human drivers would be an initial step that can test narrow lanes, without impacting a road's function too drastically.

Key Tasks Include:

- Once provincial standards are released, update road design guidelines to minimize space dedicated to vehicles and maximize space dedicated to walking and cycling.
- Convert some lanes to be AV shared lanes to test how they operate.
- Make larger conversions as adoption rate increases.

Connected Traffic Controllers

It is expected that smart intersection controllers that use V2I technology can increase the rate that traffic flows through cities. The industry has yet to arrive at a universal type of communication, so it would not make sense to invest in infrastructure until that has been established, and likely affirmed by the province. Once a standardized controller becomes available, it could be installed first at major intersections, and eventually minor ones if the benefit is deemed large enough.

Key Tasks Include:

- Look to industry and province to announce a standardized V2I traffic controller.
- Test performance of V2I controllers at select intersections.
- If deemed successful, continue to replace controllers with V2I equivalents.

Summary of Findings

The advancement of autonomous vehicle (AV) technology and implementation outpaces the associated regulatory frameworks and policies currently in place in a Canadian context. AVs are fast approaching, and have the potential to change many different aspects of mobility in municipalities ranging from suburban to urban contexts. AVs also have several implications for infrastructure, the environment, society, and the economy. As such, the City of Pickering's ITMP must address the issue of AVs, and introduce policies that leverage the technology as a tool to support a transportation network that is safe, accessible, efficient, equitable, and enhances the local economy.

There is much uncertainty in regards to how exactly AVs will take form on public roads -- persistent monitoring of key trends and drafting easily adaptable policies are key to managing this uncertainty. Policies that comprehensively and holistically prepare for AVs are necessary -- policies should namely address fundamental components such as stakeholder collaboration and partnerships, public engagement, safe AV pilot testing and programs, right-of-way and urban design, transit integration, efficient land use (repurposing parking and curbside infrastructure), AV financing and economics, infrastructure, energy and fuel sources, and social well-being.

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Appendix A : Assignment Checklist

TEAM ASSIGNMENT CHECKLIST:

Please read the checklist below following the completion of your group assignment. Once you have verified these points, hand in this signed checklist with your group assignment.

1. All team members have referenced and footnoted all ideas, words or other intellectual property from other sources used in the completion of this assignment.
2. A proper bibliography has been included, which includes acknowledgement of all sources used to complete this assignment.
3. This is the first time that any member of the group has submitted this assignment or essay (either partially or entirely) for academic evaluation.
4. Each member of the group has read the full content of the submission and is assured that the content is free of violations of academic integrity. Group discussions regarding the importance of academic integrity have taken place.
5. Each student has identified his or her individual contribution to the work submitted such that if violations of academic integrity are identified, then the student primarily responsible for the violations may be identified. Note that in this case the remainder of the team will also be subject to disciplinary action, but the penalties for the extended team members may be less severe.

Course: Plan 405

Assignment: Final Deliverables - Team 9

Date: April 9, 2018

Name (print)	Signature	Section Contributed	Section Edited
Lucas Braun		1	All
Pinremola Olufemi		2	All
Corey Yuen		3	All
Niranjan Rajevan		4	All
Ruo Meng (Lily) Sun		5	All
Felix Chau		6	All

1. Letter of submittal; executive summary; introduction; autonomous vehicle primer; municipal implications; transportation vision; challenges & solutions; recommendations; summary of findings

2. Municipal implications; transportation vision; existing policy & regulatory framework; challenges and solutions; summary of findings; acknowledgements

3. Municipal implications; case studies; Pickering context; transportation vision; challenges and solutions; summary of findings; acknowledgements

4. Municipal implications; case studies; transportation vision; challenges and solutions; summary of findings; acknowledgements

5. Executive summary; transportation vision; right of way visualizations; design of report; challenges and solutions; summary of findings; acknowledgements

6. Municipal implications; transportation vision; existing policy & regulatory framework; challenges and solutions; summary of findings; acknowledgements

Appendix B : Adapting Recommendations for Different Scenarios

Alternative 1: Shared and Fast Adoption

This scenario affects only the timeframe of the recommendations are provided. If adoption grows steadily over the next decade and market saturation is reached in 15 years, city staff will have to work tirelessly to keep pace with the rate of change.

	Timeframe				
Recommendation	Quick Wins (1-2 Years)	Short Term (3-5 Years)	Mid Term (5-10 Years)	Long Term (10-15 Years)	Market Saturation (15+ Years)
Establish AV Working Group.					
Launch AV Shuttle Pilot.					
Create Financial Tools to Promote Share Vehicle Use.					
Start AV Education Program					
Inventorize signage and lane markings, revise maintenance schedule.					
Introduce AVs into DRT Service, as first/ last mile connections or replacement for low performing routes.					
Launch EV charging station incentive program.					
Update road design guidelines to align with provincial standards. Test application of AV shared lanes.					
Create and maintain virtual map of city.					
Install first V2I traffic controllers.					
Reassess role of DRT given trends in AV costs and services.					
Update Land Use Policies to Reflect AVs					
Inventorize parking in city, and create conversion priority list. Develop tool to estimate total parking demand as a function of AV adoption.					
Introduce financial tools for promoting vehicle sharing, and adjust as necessary.					
Apply new road design standards and gradually reconfigure municipal roads.					

Launch policies and incentives to cause parking conversions.					
Upgrade additional intersections to V2I controllers.					

Alternative 2: Private and Slow Adoption

This scenario represents what is essentially a 'business as usual' timeline: private auto ownership remains predominant, and slowly becomes automated. It is assumed that the initial adoption is primarily undertaken by the wealthy, which is why the provision of AV infrastructure is slowed in most cases. If the amount of private vehicles continues to increase (especially as the elderly and disabled gain access to this mobility), it is unlikely that significant reductions to the supply of parking can be made. The financial disincentives of single occupancy would be stricter than in shared scenarios.

	Timeframe				
Recommendation	Quick Wins (1-2 Years)	Short Term (3-5 Years)	Mid Term (5-10 Years)	Long Term (10-15 Years)	Market Saturation (20+ Years)
Establish AV Working Group.					
Launch AV Shuttle Pilot.					
Create Financial Tools to Promote Share Vehicle Use.					
Start AV Education Program					
Inventorize signage and lane markings, revise maintenance schedule.					
Introduce AVs into DRT Service, as first/last mile connections or replacement for low performing routes.					
Launch EV charging station incentive program.					
Update road design guidelines to align with provincial standards. Test application of AV shared lanes.					
Create and maintain virtual map of city.					
Install first V2I traffic controllers.					
Reassess role of DRT given trends in AV costs and services.					

Introduce financial tools for promoting vehicle sharing, and adjust as necessary.					
Apply new road design standards and gradually reconfigure municipal roads.					
Upgrade additional intersections to V2I controllers.					
Increase road capacity of arterials if necessary.					

Alternative 3: Private and Fast

The difference between Alternative 3 and Alternative 2 is the same as that between Alternative 1 and the base recommendations; the recommendations do not change, but their timelines become tighter. In this scenario VKT is expected to increase significantly, meaning that quick provision of supportive infrastructure is needed to mitigate the effects on congestion. Despite these efforts, increased road capacity may be needed.

	Timeframe				
Recommendation	Quick Wins (1-2 Years)	Short Term (3-5 Years)	Mid Term (5-10 Years)	Long Term (10-15 Years)	Market Saturation (15+ Years)
Establish AV Working Group.					
Launch AV Shuttle Pilot.					
Create Financial Tools to Promote Share Vehicle Use.					
Start AV Education Program					
Inventorize signage and lane markings, revise maintenance schedule.					
Introduce AVs into DRT Service, as first/last mile connections or replacement for low performing routes.					
Launch EV charging station incentive program.					
Update road design guidelines to align with provincial standards. Test application of AV shared lanes.					
Create and maintain virtual map of city.					

Install first V2I traffic controllers.					
Reassess role of DRT given trends in AV costs and services.					
Introduce financial tools for promoting vehicle sharing, and adjust as necessary.					
Apply new road design standards and gradually reconfigure municipal roads.					
Upgrade additional intersections to V2I controllers.					
Increase road capacity of arterials if necessary.					