Turning Transportation

Challenges and Opportunities Presented to the City of Vancouver by Autonomous Vehicles

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Greenest City Scholars Report
August 31, 2016

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Chapter 1: Executive Summary

1.1 Background

This Greenest City Scholars report was prepared to support the "Preparing Vancouver for Autonomous and Driverless Cars" motion from February 2016 which directs City staff to investigate the implications of autonomous vehicle technology on long-term plans and strategies and the best ways to approach the challenges and opportunities the technology presents. The Greenest City Scholars program is jointly managed by the City of Vancouver and the University of British Columbia.

1.2 Methodology

This report reviewed a variety of literature to find trends, data and future projections for AV technology. This review was supplemented with interviews from City of Vancouver staff as well as researchers from UBC's Transportation Infrastructure and Public Space Lab, consultants and Translink staff. This information was used to determine future scenarios, a series of guiding principles for future policies, and immediate actions related to the introduction of autonomous vehicle technology.

1.3 Report Summary

In the next two decades, automotive technology revolutions are likely to significantly impact urban transportation. Autonomous vehicles – not unlike the locomotion engine or the automobile – could significantly impact transportation networks and land development patterns in Metro Vancouver, across British Columbia, and beyond.

This report brings together current research on autonomous vehicles in order to anticipate potential changes, challenges and opportunities. AVs may improve transportation safety and accessibility across the region; free up large amounts of space currently required for parking; and complement active transportation and public transit. On the other hand, they may exacerbate sprawl; encourage auto-oriented development and discourage walking and cycling in compact communities.

AV technology is not inherently beneficial or harmful in and of itself. It is the policy decisions made today that will move Vancouver towards, rather than way from, the city we aspire to be. Given the rapid advancement of AV technology and the potential to significantly extend commutes, working with regional and municipal partners as soon as possible is vital.

1.4 AV Policy Guideline Recommendations

Many Av-related policy decisions will be made in the near future, despite many uncertainties. To facilitate these decisions, the following list of guidelines should direct these decisions:

1. **Mobility** – Ensure AV technology complements active transportation and mass transit, the healthiest, cheapest, most resilient, and most efficient urban transportation networks for people.
2. **Health** – Support active lifestyles by making walking and cycling the easiest and most convenient transportation options for most trips.
3. **Safety** – Improve safety by reducing transportation-related fatality and serious injury rates.
4. **Affordability** – Ensure affordable transportation options for people of all income levels. Encourage a shared ACES approach over privately owned vehicles.
5. **Accessibility** – Make it easier for people with limited mobility to access destinations and travel within the region.
6. **Environment** – Work towards a zero transportation-emissions future, and support AV policies that encourage compact, complete communities that preserve ecological habitat and protect agricultural land.
7. **Economy** – Support a thriving local economy as well as the City's role as an international port, and encourage innovation in support of green industry.
8. **Public Life** – Support vibrant public spaces that encourage social interaction.
9. **Resiliency** – Ensure the transportation system is resilient to changes in fuel prices, climate change, earthquakes and sea level rise, unstable weather patterns, electricity outages, and cybersecurity threats.
10. **Equity** – Encourage open-source platforms, as well as adaptable technology and infrastructure that encourages innovation while ensuring a level playing field for industry partners and private companies.
11. **Data Sharing and Privacy** – Collect meaningful aggregate data to improve transportation planning while protecting privacy.
12. **Immediacy** – Begin working with regional partners today to create a coordinated policy response.

1.5 Immediate Actions

In spite of uncertainties, there are many actions that can be taken now to prepare for the introduction of AVs to Vancouver.

1. Establish a regional AV technology working group, led by TransLink and Metro Vancouver to research emerging issues, develop regional policies, and work with the private sector and other higher levels of government.

2. Establish ongoing dialogue with other major cities in Canada and across North America to develop a coordinated approach and advocate for AV policies that support compact, sustainable urban development.

3. Plan and invest in infrastructure that moves Vancouver closer to a green future where shared autonomous vehicles support a multi-modal transportation system and discourage private vehicle ownership.

4. Continue to work with regional partners to develop a comprehensive regional mobility pricing strategy that prioritizes active transportation and mass transit, and that is sensitive to travel time, congestion levels, and vehicle occupancy rates.

5. Continue to reinforce the Transportation 2040 modal hierarchy in new developments, community plans, transportation decisions, and civic infrastructure.

6. Consistent with Transportation 2040 direction, **future proof** parking in new development by designing off-street parking to be a sharable resource that can be easily adapted to different uses.

7. Consider ways to retrofit parking in existing buildings to be more easily sharable by non-residents, and support conversion to other uses.

8. Consider how street space might be adapted over time as private vehicle ownership declines.

9. Support pilot projects provided they are consistent with the above-noted principles.

Chapter 2: Context

2.1 Report Context

Emerging trends in automotive technology have the potential to profoundly influence how cities are built, how people get around, and how goods and services are delivered. Traditional auto manufacturers as well as technology companies like Apple & Google are investing billions of dollars into the development of new **Autonomous Vehicle (AV)** technology. The widespread implementation of this technology, which will likely be commonplace by 2020-2025, is forecasted to become the primary means of transportation by 2040 (Ticoll, 2015).

Potential benefits include:

- significantly reduced vehicle collisions and fatalities and a related decrease in healthcare costs and insurance rates;
- increased mobility options for those who are currently restricted from driving (including children, seniors and persons with disabilities);
- increased space for walking, cycling, transit, and other non-auto oriented uses through:
    - improved utilization of existing road spaces (since AVs may be able to travel more closely together); and
    - reduced need for both on-street and off-street parking (if private vehicle ownership decreases and vehicle utilization increases);
- improved efficiency and effectiveness of public transit, taxi, car-sharing, and goods movement fleets;
- decreased emissions through vehicles that are lighter and powered by clean energy;
- improved capabilities to implement mobility pricing;
- improved data collection and transportation planning tools; and
- regained driving time leading to productivity gains.

Potential challenges include:

- increased auto ownership, driving, and urban sprawl;
- decreased walking, cycling, and transit trips;
- decreased support for walking, cycling, and mass transit infrastructure;
- decreased City and regional revenues (e.g. parking revenue and fuel taxes);
- increased threats to cybersecurity;
- increased potential for breaches in privacy through information collected; and,
- reduced employment in industries such as delivery, parking, and collision repairs; and,
- increased transportation issues during rare events (e.g. extreme weather and utility failures).

There are also numerous uncertainties and confusion regarding:

- regulations and standards at the local, provincial, federal, and international level;
- levels of public acceptance;
- insurance and liability implications; and,
- the transition period where there will be a mix of regular and automated vehicles.

Technology in and of itself is inherently neither good nor bad. While automotive and technological sectors are investing heavily in an automated future, their decisions may not always align with the public's best interest. It is up to cities and other levels of government to create the vision for the future we want, and then to develop policies to support that vision.

Radically different potential futures are possible, depending on whether automated vehicles are predominantly shared or privately owned, how different transportation modes are prioritized, and how we control land use and limit (sub)urban sprawl.

2.2 Council Motion Context

This Greenest City Scholars report supports the "Preparing Vancouver for Autonomous and Driverless Cars" motion from February 2016, which includes the following motions:

THEREFORE BE IT RESOLVED THAT Council direct staff to report back on:

- *the implications, both positive and negative, of this technology on the City's transportation, land use, economic and sustainability plans, as well as the steps necessary to update those plans; and*
- *the views of the City's planning, transportation and technology experts on the best ways to maximize the benefits of this technology for the City and its economy while mitigating potential negative impacts.*

2.3 Greenest City Scholars Program

This report was prepared for the Greenest City Scholars program, jointly managed by the City of Vancouver and the University of British Columbia. For the program, every scholar creates a project within 250 hours related a goal within the City's Greenest City Action Plan (2015a).

AVs have the potential to impact a number of Greenest City goals, including:

- *Make walking, cycling and public transit preferred transportation options.*
- *Secure Vancouver's international reputation as a mecca of green enterprise.*
- *Vancouver residents enjoy incomparable access to green spaces including the world's most spectacular urban forest.*
- *Eliminate dependence on fossil fuels.*
- *Achieve a one-planet ecological footprint.*
- *Breathe the cleanest air of any major city in the world.*

2.4 Research Questions

This project centres around three research questions:

1. How will autonomous and connected vehicles impact urban environments, road capacity, vehicle ownership rates, parking requirements, general mobility and mode share?
2. How will new vehicle technologies impact the assumptions, objectives, and directions of the Greenest City Action Plan, Transportation 2040 Plan, Renewable City Strategy, and other key municipal and regional strategies?
3. What Vancouver-specific considerations will help local planners and decision-makers prepare for the future?

2.5 Methodology

This report is based on a review of academic, industry, government and popular literature to find trends, data and future projections for AV technology. This review was supplemented with interviews from City of Vancouver staff as well as researchers from UBC's Transportation Infrastructure and Public Space Lab, consultants from CH2M and Translink staff. The report pulls this information together and makes recommendations to ensure changes in automotive technology support the City's transportation, city-building, and sustainability objectives.

Chapter 3: Trends in Autonomous Vehicle Technology

Vehicle trends are emerging and merging to create ***autonomous, connected and electric (ACE)*** *vehicles that will likely be shared rather than privately owned. Any policy decisions should also assume vehicles will communicate with their environment and charge electrically.*

Vehicle automation exists on a spectrum from non-automated to full automation, usually measured by the Society of Automotive Engineers (SAE) or the U.S. National Highway Traffic Safety Admission (NHTSA) scales (SAE, 2014; NHTSA, 2013). This report will refer only to the SAE standards (see Figure 1).

Currently, most AV technology available commercially falls under SAE level 2 or 3, with tasks divided between vehicle and driver. These partially automated systems are usually grouped together as **Advanced Driver Assistance Systems (ADAS).** They include automatic braking, intelligent cruise control and self-parking systems. These systems are already becoming standard on new vehicles.

Although the Telsa Model S and Google Car are both well-known as "driverless" vehicles, they have very different capabilities. The Model S is only at level 3 so when its ADAS systems are engaged, the driver must still be ready to intervene at anytime. On the other hand, the Google Car is closer to level 4 or 5 and the driver is not expected to monitor the vehicle. Except where noted, the term "autonomous vehicles" in this report will be referencing level 5 automated technology when vehicles are truly autonomous.

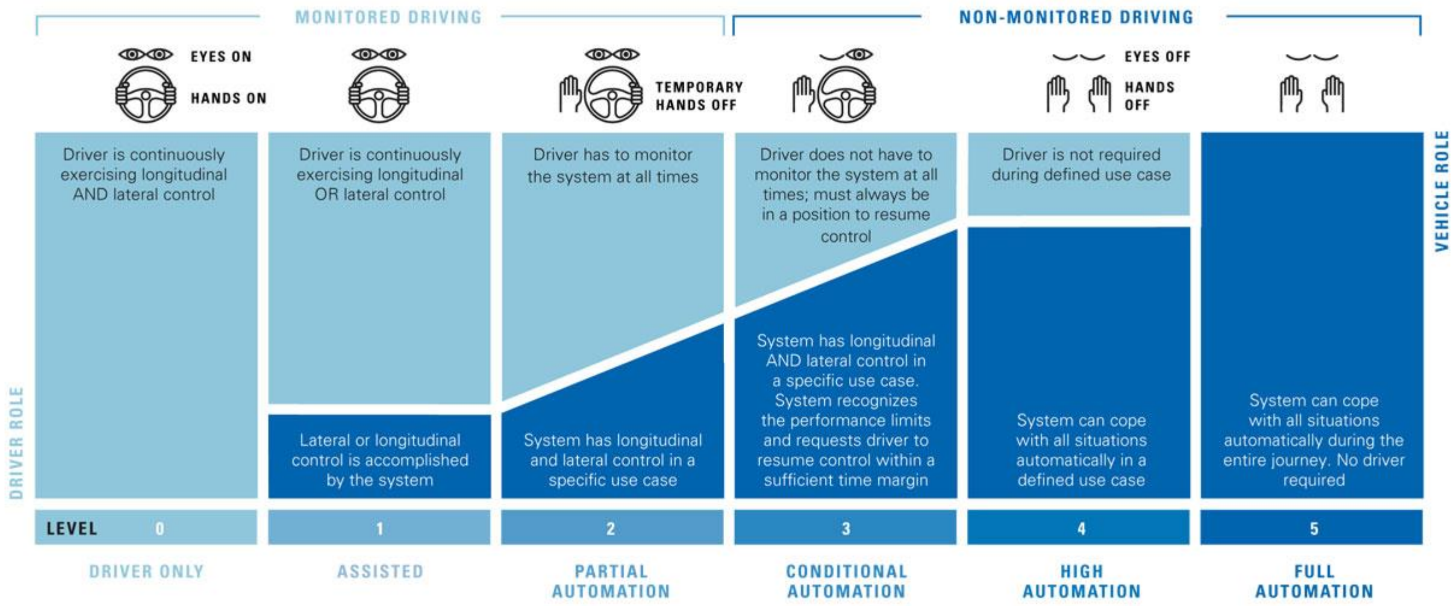

Figure 1: The SAE stages of automation marking the changing role of the driver and vehicle.

3.1 Autonomous, Connected, Electric & Shared Vehicles

As AVs progress, most researchers, developers and manufacturers expect autonomous vehicle technology to merge with other vehicle technology to become **Autonomous, Connected and Electric (ACE)** vehicles. The assumption that AVs will be ACE vehicles is built into this report.

In addition to the term ACE, some experts are beginning to use **ACES** to describe a model of AV that is also shared. This report will separate shared vehicles from these other trends and use the term **Shared Autonomous Vehicles (SAV)** to specifically refer to these vehicles. SAV will likely be part of **Mobility as a Service (MaaS)** transportation networks, explained in greater detail in section 3.1.4.

3.1.1 Connected Vehicles

Currently, most AVs navigate using information from their sensory system which usually includes LIDAR, global positioning systems (GPS), ultrasound and photography systems as well as long-, medium- and short-range radars. These independent systems provide the sensory information for the vehicle to navigate safety.

In the future, most vehicles will also be **Connected Vehicles** (CVs) and will augment this sensory information with information from the environment. Several types of overlapping communication systems will provide a variety of connections (see Table 1). By adding these capabilities to vehicles, CVs will become part of the **Internet of Things**. Passengers will connect their personal or onboard devices to the internet using a parallel system for security purposes.

Table 1
Types & Purposes of Connected Vehicle Communication Systems

Type	Communication	Main Purpose
V2I	Vehicle to Infrastructure	Connect vehicle with its local infrastructure
V2V	Vehicle to Vehicle	Connect with other vehicles
V2P	Vehicle to Pedestrian	Connect with pedestrians
V2D	Vehicle to Device	Connect with user personal device
V2G	Vehicle to Grid	Connect with power grid (for electric vehicles)
V2X	Vehicle to Everything	Collective name for above types of communication.

Google and other companies like Volvo are currently designing their vehicles to operate without the need for V2X communication. Their vehicles will be built to rely on sensory information and detailed 3D maps of the driving environment pulled from the cloud (Ticoll, 2015). However, the vehicles will likely need to be V2X connected in the future to receive and respond to requests from other road users and infrastructure, for example, a request to pull over from an emergency vehicle.

Connected vehicles will be able to tap into V2X communication and information from the cloud to converse, rather than react to their environment. At a policy and planning level, communicating directly with vehicles allows for additional regulation and monitoring, but could add significant cost which will be explored in the digital infrastructure section of this report.

3.1.2 Electrical Vehicles

AV technology is evolving with **Electric Vehicle** (EV) technology. Since **ACE** vehicles will be able to monitor their charge, find a charger nearby and drive there without assistance, they will likely reduce “range anxiety” and speed EV uptake. Even though battery technology is not advancing at the rate of AV technology, most manufacturers are focusing their research and design on autonomous, electric vehicles.

3.1.3 Shared Autonomous Vehicles

This term encompasses a variety of models of carshare and rideshare services. SAVs will be more convenient than carshares as they can drive to the user. They can be managed and run by a public agency or private company and could have different “tiers” of membership. This could include “shared” vehicles that are single occupancy, but used by multiple people. In this report, the term SAV refers to vehicles that have the capacity for multi-occupancy unless a single-occupancy SAV is referenced.

3.1.4 Mobility as a Service Networks

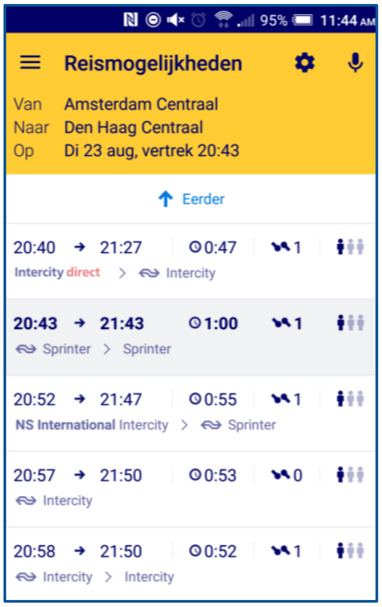

Figure 2: The Netherlands' national rail service mobile app. Users choose between types of trains and routes and pay for their trip on the app. In a MaaS system, choices would include carshare, bikeshare and other modes.

Mobility-as-a-Service, or **Transportation-as-a-Service (TaaS)** is transportation system that integrates a number of services such as bikeshare, carshare and mass transit into a single trip location to plan and pay for a trip. According to Godsmark, Kirk, Gill & Flemming (2015), households choosing MaaS instead of a privately owned vehicle will save an estimated $2,700 each year. Although time and cost may vary based on type of service, a user can plan and pay for their whole journey at a single point, likely a mobile app (see Figure 2). Because the relative time and financial choices are clear to MaaS users, complex mobility pricing to encourages off-peak travel, active transportation or multi-occupancy vehicles choices can be implemented.

3.1.5 AV Vehicle Design

AVs are typically imagined as similar in design to today's vehicles with four wheels and a side entrance, although more creative designs are emerging (see Figure 3). In the future, vehicle design will likely vary significantly based on the vehicle's purpose from large shuttles carrying groups of people to single-occupancy vehicles. Some may even shrink to become small, purpose-built robots for the delivery of groceries and other goods. A group of individual AVs may also be able to brake and maneuver as a unit on highways using **platooning** technology.

Figure 3: A design for AV different in form from today's vehicles.

The technology for AV vehicles is advancing rapidly and the type of software and hardware advances that will be needed are still relatively unknown. The range of vehicles built (for example, single- vs. multiple-occupancy) and the software they integrate with will be based on regulation and policy from all levels of government.

3.2 The Entry of AVs into the Market and the Public Realm

The City of Vancouver's long term planning goals are ambitious and progressive. In order to achieve these goals, the response to the introduction of AVs must be equally forward-thinking. These goals will not be met if research and decisions related to AV technology are delayed until the next significant update of the Transportation Strategy (City of Vancouver, 2012) and other long-range plans.

Industry experts suggests that by 2040, AVs will be the primary means of transport.

Partially automated vehicles are already available and many manufacturers believe that autonomous vehicles will be on the market by 2020 (Canadian Automated Vehicles Centre of Excellence [CAVCOE], 2015; Isaac, 2015). Industry experts suggests that by 2040, AVs will be the primary means of transport (Ticoll, 2015). The time between the introduction of automated technology and most vehicles being autonomous is known as the transition period.

Market surveys indicate a high level of public interest in AVs. A recent global survey suggested that 52% of global consumers are already likely or likely to choose to ride in a self-driving car if they can avoid finding parking space, avoid maneuvering to park and multi-task during their trip (World Economic Forum, 2015). They are even willing to pay more for AVs and consider sharing AV taxis for a discounted rate. An ICBC survey of B.C. residents showed they still have concerns about the vehicle safety, but are interested in the potential benefits (Mackin, 2016). The City could survey residents to create a baseline for interest and see potential concerns before AVs are introduced.

In 1900, 4,192 cars were sold in the United States. By 1912 that number had risen by 8000% percent to 356,000.

Although the rate of adoption may be slower than currently predicted, this rate is not without precedent. In 1900, 4,192 cars were sold in the United States. By 1912 that number had risen by 8000% percent to 356,000 (Godsmark et al., 2015). (Financially, the sale of AV fleets to companies rather than the sale of privately owned vehicles to individuals may make large-scale rollout more viable.)

During the introduction of motor vehicles, governments at all levels allowed the automotive industry to set standards. This resulted in patterns of city development heavily dependent on private automobiles. Streets, formerly public spaces for walking, cycling, and transit use, were turned over to automotive drivers so they could travel faster and further with fewer obstacles. Infrastructure and policy decisions further reinforced the primacy of the private automobile and enabled people to live further from the city in auto-oriented neighbourhoods resulting in the suburban sprawl that many cities struggle with today. AVs cannot change the past but regulation and policy directing their use can help us move toward a greener, more sustainable future.

Chapter 4: Future Planning Moving Forward to A Green Future

4.1 Future Scenarios after AV Introduction

AV technology, along with a wave of new technologies like 3D printing, is a disruptive or, optimistically, transformative technology that will significantly change the way the city and industries are organized. Other disruptive transportation technologies such as the steam engine, combustion engine or air travel outline the range of ripple effects that may flow from AV technology. It will be policy and planning, not the technology itself, which determines whether impacts are positive or negative.

To illustrate the possible futures that AVs may bring, many policy and industry papers use a spectrum or matrix of scenarios (Costa Maia & Meyboom, 2015; Isaac, 2015; Translink, 2016). The matrix from Translink outlines possible outcomes for different occupancy and mobility scenarios (see Table 2). Of the scenarios describe, "Coordinated Mobility" is closest to representing a future consistent with municipal and regional sustainability strategies.

Table 2
Future Scenarios after the introduction of AVs (Adapted from Translink, 2016).

		Vehicle Occupancy	
		Single-Occupancy	Multi-occupancy
Mobility	Multi-modal	***Uncoordinated Mobility***: Mass transit is prominent. 'Last mile' trips are provided by many modes connected to mass transit in urban areas and suburban centres. Private vehicle ownership remains high outside of centres.	***Coordinated Mobility***: Mobility, rather than a transportation mode, is bought. Modes integrate seamlessly and operate under a public transportation system umbrella. The efficiencies of the core support the 'last mile' trips at the periphery.
	Auto-dependent	***Status Quo***: More personally owned vehicles and urban congestion. People commute longer distances potentially changing patterns of density. Public transit remains viable.	***Motor City***: Cars remain prominent but they are shared vehicles (as fleets or individually owned vehicles). Transit use and services have declined. Parking is now located in large facilities outside core.

4.2 A Greenest City Scenario

The following is a detailed vision of how automated vehicles could support a progressive Vancouver in 2050 that aligns with current planning documents. In this scenario, Vancouver councils, as directed by residents, have made choices to enforce Vancouver's place as a Green City on the world stage. Vancouver remains a green, resilient, efficient, accessible and vibrant city with a range of mobility choices enhanced by ACE technology as it has achieved the Greenest City Action Plan goals and other long-term plans.

Safety & Health

- AVs are attentive and responsive to those walking, cycling or taking active transportation vehicles.
- Years without traffic fatalities or serious injuries are the norm.
- Over 80% of trips under 15 minutes are made by cycling and walking.

"As a traffic engineer, I know how much safer our roads are. Unlike when I was in school, my kids can bike to school on their own."

Mobility

- Personal motor vehicle ownership has decreased.
- SAVs are seamlessly integrated into a multi-modal transportation that prioritizes active transportation in walkable, bikeable communities oriented around mass transit.
- Almost all modes of transportation, public and private, are accessed through the Compass app (or street-side kiosk).
- Different tiers and types of vehicles meet a diversity of needs.
- Mobility pricing sensitive to trip length, off-peak travel and vehicle occupancy is integrated into the app and also applied to personal motor vehicles & delivery vehicles encouraging ridesharing and efficient routes.
- Any **deadhead trips** without passengers face additional charges.

"I used to drive to work every day. Now I take a shuttle to the Skytrain in the morning and bike back from the station on the way home."

Accessibility & Affordability

- A positive cycle of increasing revenues & increasing service has expanded mass transit and last mile options, regardless of time of day.
- Mass transit & SAV trips are affordable and efficient.
- Some outlying areas are still underserved by transit, encouraging density.
- Speciality vehicles with attendants are available for people with disabilities and seniors. These groups report less isolation and larger support networks.
- Concession pricing is available for a variety of users, regardless of location.

"I like knowing a vehicle can always pick me up from work, even when I finish working at 3 or 4 A.M."

Economy:

- Local tech firms produce modeling software for short- and long-term planning.
- Vancouver is world-leader in equitable and sustainable AV programming.

Environment

- The Metro Vancouver region has not expanded geographically and, after a small initial increase, the average commute time has fallen slightly. Long commutes are rare.
- Density continues to be added along major streets and Transportation Oriented Developments (TODs).
- All light vehicles have non-carbon-based fuels and air quality has improved.

"I was able to convert the garage in a laneway house for my mother-in-law. Our whole neighbourhood is doing something similar. Our back lane is a great public space."

Community

- Transportation remains the backbone of social and cultural life in Vancouver. Residents are able to get to and from events and social gatherings with ease, regardless of the time of day.
- With more time to work or sleep on commutes, residents report they spend more time with friends and family.
- Regardless of transportation mode, Vancouver residents and workers report high levels of community connections and involvement.
- Some former on-street parking has been reallocated as mixing, pick-up or drop-off space. The majority of the space has been reallocated to create more space for walking and cycling, as well as improved public space and affordable housing. The street is public space.

"I walk to the grocery store more than I did when I owned a car. The distance to the store is just a 5-minute walk from the neighbourhood AV pickup spot."

Resiliency:

- Vancouver remains resilient thanks in part to overlapping transportation networks and AV technology.
- The transportation system is able to respond quickly to short and long-term changes in density and use.
- Climate change has made extreme weather patterns more common. AVs help evacuate residents with minimal staff.
- Walking and cycling networks in compact communities allow residents to purchase goods even when transit and motor vehicle networks are not functioning.
- The transportation system relies on locally generated electricity rather than external energy inputs.

"I have a private AV and rent it out to other people through a private company. Once it's too old, I won't buy another vehicle. Transit is cheaper option for my family now that my kids are in middle school."

The future outlined above is possible but only with progressive policies that encourage active transportation, compact land use, and shared rather than privately owned AVs. Policies must also in place to discourage long motor vehicle trips and auto-oriented sprawl. We should be wary of any promises that AV technology alone will improve our lives without local, provincial and national regulation supporting this future.

4.3 Scenarios & Chart

Each future transportation scenario proposed will bring positive and negative effects to Vancouver. Detailed charts of policies and the positive or negative effect of AVs can be found in the policy paper, *Driving Change* (Ticoll, 2015). However, Table 3 summarizes the potential effects of Translink's transportation scenarios as well as the Greenest City scenario on different outcomes related to long-term City goals. The Greenest City scenario builds on the Coordinated Mobility scenario by further integrating Greenest City goals and other long-term City planning goals.

Table 3:
A comparison of future transportation scenarios (Adapted from Translink, 2016).

Outcomes	Scenarios				
Outcome measurement: (+) More than present level (–) Less than present level (=) Equal to present level	Status Quo	Motor City	Uncoordinated Mobility	Coordinated Mobility	Greenest City
Safety					
Traffic fatalities	–	–	–	–	–
Health					
Active transportation use	=	–	=	+	+
Mobility					
Personal vehicle ownership	=	–	–	–	–
Vehicle Kilometres Travelled (VKT)	=	–	–	–	–
Accessibility					
Unlicensed groups mobility	–	+	+	+	+
Affordability					
Individual transportation costs	=	–	–	=	–
Low income mobility	=	–	?	–	+
Economy					
Local economy	Undetermined				+
Job opportunities	Undetermined				?
Efficient goods movement	=	=	+	+	+
Environment					
Compact communities	Undetermined				+
Greenhouse gas emissions	+	=	–	–	–
Community					
Community connections	Undetermined				+
Parking requirements	=	=	–	–	–
Resiliency					
Flexible transportation network	+	–	+	+	+
Response to hazards	Undetermined				+
External energy inputs	+	=	–	–	–

4.4 AV Policy Guidelines

Given the high levels of uncertainty around emerging automotive technology, setting strict guidelines and rules around AV use in Vancouver would be premature. Instead, future transportation policies and decisions should consider emerging technology as an additional lens to view decisions through. The following principles build upon Greenest City, Transportation 2040, Healthy City and Metro Vancouver Regional Growth Strategy goals (City of Vancouver, 2012; City of Vancouver, 2015a; City of Vancouver, 2015b; Metro Vancouver, 2015b). They provide a framework to develop comprehensive transportation policies and decisions that include AVs.

1. **Mobility** – Ensure AV technology complements active transportation and mass transit, the healthiest, cheapest, most resilient, and most efficient urban transportation networks for people.
2. **Health** – Support active lifestyles by making walking and cycling the easiest and most convenient transportation options for most trips.
3. **Safety** – Improve safety by reducing transportation-related fatality and serious injury rates.
4. **Affordability** – Ensure affordable transportation options for people of all income levels. Encourage a shared ACES approach over privately owned vehicles.
5. **Accessibility** – Make it easier for people with limited mobility to access destinations and travel within the region.
6. **Environment** – Work towards a zero transportation-emissions future, and support AV policies that encourage compact, complete communities that preserve ecological habitat and protect agricultural land.
7. **Economy** – Support a thriving local economy as well as the City's role as an international port, and encourage innovation in support of green industry.
8. **Public Life** – Support vibrant public spaces that encourage social interaction.
9. **Resiliency** – Ensure the transportation system is resilient to changes in fuel prices, climate change, earthquakes and sea level rise, unstable weather patterns, electricity outages, and cybersecurity threats.
10. **Equity** – Encourage open-source platforms, as well as adaptable technology and infrastructure that encourages innovation while ensuring a level playing field for industry partners and private companies.
11. **Data Sharing and Privacy** – Collect meaningful aggregate data to improve transportation planning while protecting privacy.
12. **Immediacy** – Begin working with regional partners today to create a coordinated policy response.

4.5 Immediate Actions to Prepare for the Introduction of AVs

The following actions should be implemented in the near term:

1. Establish a regional AV technology working group, led by TransLink and Metro Vancouver to research emerging issues, develop regional policies, and work with the private sector and other higher levels of government.
2. Establish ongoing dialogue with other major cities in Canada and across North America to develop a coordinated approach and advocate for AV policies that support compact, sustainable urban development.
3. Plan and invest in infrastructure that moves Vancouver closer to a green future where shared autonomous vehicles support a multi-modal transportation system and discourage private vehicle ownership.
4. Continue to work with regional partners to develop a comprehensive regional mobility pricing strategy that prioritizes active transportation and mass transit, and that is sensitive to travel time, congestion levels, and vehicle occupancy rates.
5. Continue to reinforce the Transportation 2040 modal hierarchy in new developments, community plans, transportation decisions, and civic infrastructure.
6. Consistent with Transportation 2040 direction, **future proof** parking in new development by designing off-street parking to be a sharable resource that can be easily adapted to different uses.
7. Consider ways to retrofit parking in existing buildings to be more easily sharable by non-residents, and support conversion to other uses.
8. Consider how street space might be adapted over time as private vehicle ownership declines.
9. Support pilot projects provided they are consistent with the above-noted principles.

Chapter 5: Governance

In the United States, regulatory conflicts are causing confusion which could hinder the harmonization of Canadian and American AV standards. Before AV technology sees a large-scale rollout in Canada, there are still jurisdictional issues to be worked out between Provincial and Federal Governments.

5.1 American Regulations

In the United States, different levels of governments have created contradictory legislation due to jurisdictional confusion. At the national level, the NHTSA has chosen to interpret 'driver' as including a self-driving system. This does not allow AVs manufacturers to remove the human-controlled interface and move to full automation immediately, but signals tentative support from the American federal administration (Lienert & Shepardson, 2016).

Several states are also authorizing the operation of AVs within their boundaries, although the rules are varied on the allowed level of automation (Luckerson, 2016). In Florida, AVs can drive on any roadway and be operated by any licensed person, although the driver does not need to be in the vehicle (contradicting NHTSA regulations). Florida also allows the testing of larger truck platoons which has attracted companies working on this technology. Within California, legislators and the Department of Motor Vehicles have proposed contradictory legislation and regulations as to whether drivers need to be able to take over vehicle (Harris, 2016). This variety of state legislation and inconsistency between different American levels of government could delay large-scale vehicle roll-out in the United States and Canada.

Case Study: Amsterdam Declaration
(Amsterdam, Netherlands)

In April, an inter-national agreement between governments in the EU and auto-manufacturers committed the nations to working to create a unified set of regulations by 2019. This includes practical guidelines as well as commitment to "learning by experience" approach and knowledge sharing ("Amsterdam Declaration", 2016).

Figure 4: AV car during a trial in Amsterdam.

5.2 Federal & Provincial Regulation

The inter-governmental regulatory conflict in the states may cause some delay in Canada as the Canada Transportation Act Review report have recommended harmonizing the Canadian federal regulatory framework with the United States, as recommended in the Canada Transportation Act Review Report (Government of Canada, 2016). The federal government should also avoid conflict with the provinces on these jurisdiction issues and has already made positive steps in that direction by signing agreements on AV development with the Ontario government.

The City should support a working relationship between provincial and federal governing agencies whenever possible. Lauren Isaac (2015) has prepared a very thorough report of how these relationships might be navigated that could serve as a guide at the national and regional level, as well as the local level.

Currently, there are several jurisdictional issues to be decided in order to test vehicles in Canada. Unlike many countries, Canada and the United States are not signatories to any international treaties dictating how drivers control their vehicle.[1] At a national level, Transport Canada controls vehicle standards through the Motor Vehicle Safety Act including the testing, manufacturing and deployment of vehicles (CAVCOE, 2015). According to the Canada Transportation Act Review, this would include the regulation of AV readiness, manual override features, driver credentials and insurance requirements (Government of Canada, 2016).

An updated Act would allow the provinces to draft new laws related to the regulation of AVs. However, as the distinction between vehicle and driver blur, these levels of government must redefine their regulatory roles and create new complementary standards before AVs see a large-scale rollout.

5.3 Municipal Regulation

At the local level, the City of Vancouver will likely have minimal expertise to bring to the standards and regulations discussions. However, the City does still have control over street design and infrastructure which will give them say at this scale. They should also encourage sustainable and equitable standards for modeling, software and design of vehicles and technology. By working with RMCP and VPD, the City can support the enforcement of existing and potential new legislation and regulations related to the safety and sustainability of AVs.

Although more research is needed, regulating the emission of vehicles in the City or in different zones may be possible. The City may even have the authority to create "AV Only" zones closed to non-AV vehicles (and open to those travelling by foot or bike). This report explores these ideas and many other possible AV-related plans and policies the City could consider to meet long-term planning goals.

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[1] Many countries are signatories on the 1968 Vienna Convention on Road Traffic which required drivers to "at all times be able to control his vehicle" (Lienert, D., & Shepardson, P., 2014). In 2014, the international law was amended to require that a driver be present and able to take the wheel at any time.

5.4 Regulation Recommendations

- Support a working relationship between the Province of B.C. and Federal Government in regards to AV standards for roads, vehicles, transit safety, mobility pricing, fines, penalties and data sharing.
- Encourage AV research and testing at the federal and provincial levels including research into AV equity, liability, security and privacy.

Chapter 6: International, National or Provincial Concerns

AVs have become a topic of interest in popular literature as journalists raise questions surrounding the digital security and ethics of these vehicles. Job automation has become a pressing concern as well as AV technology will transform or remove many jobs from the field. The regulatory and policy response to these questions will happen at the provincial and federal level, but City Council and staff should be aware of the context of these barriers to AV integration and how they might affect long-term planning goals.

6.1 Privacy & Security

6.1.1 Data Management

Like computers or smart phones, AVs could hold vast amounts of data about their trips, environment and users and will be part of larger networks of vehicles and travel demand management systems. The BC Freedom of Information and Privacy Association (BC FIPA), has identified many pieces of data that could be stored in the vehicle or the cloud including records of performance, location, route history and even exact movements in the moments before a collision (BC FIPA, 2015).

A vehicle could also collect and store individual schedules, multimedia preferences and health status. If users access the internet through an AV, they will provide the same information as they would on any computer including consumption habits and personal communications. AVs can even collect information about their environment as they move through it.

Obviously, this type of data can be very useful to different levels of government, law enforcement, private corporations and cyber thieves. It could be used for a wide range of purposes including transportation planning, improving vehicle performance and design, mobility pricing, targeted marketing, usage-based insurance, and identifying individuals.

Fagnant & Kockelman (2015) have identified five important questions for the management of AV data (p. 178):

- "Who should own or control the vehicle's data?
- What types of data will be stored?
- With whom will these data sets be shared?
- In what ways will such data be made available?...
- For what ends will they be used?"

Many of these questions may already be covered under Canadian privacy laws, however updated regulations will be needed. Privacy watchdog organizations and experts have already made suggestions regarding data generation, collection and retention. The BC FIPA has suggested the adoption of "Privacy by Design" which includes security design in the creation of AVs and their related systems (BC FIPA, 2015).

6.1.2 Data Security

AVs also represent a significant security threat due to their connection to large information networks. Each AV could become an entry point into a wider network for cyberattacks or even external surveillance through sensory devices.

At the micro-scale, a hacker may be able to override speed or behaviour limits set within the vehicle's code or communicated through connected infrastructure, if a vehicle's digital infrastructure is designed incorrectly. They may be able to "trick" AVs with false data that reduces their time or costs while decreasing safety and energy savings.

The likelihood of these types of criminal actions will be partially determined by individual choice and public perception, much like seat belt use, fare evasion or online music theft. However, advances in digital security since the creation of computers means that V2X communication and the digital infrastructure of vehicles were built with security architecture in mind, rather than as an afterthought.

Advances in digital security since the creation of computers means that V2X communication and the digital infrastructure of vehicles were built with security architecture in mind, rather than as an afterthought.

Separating communication and critical driving systems can further reduce the risk that any attacker would be able to gain control and injure a user. As regulation and monitoring improve, risks will hopefully be further decreased.

6.1.3 Data Collection

Privacy concerns will need to be weighed against the potential uses for some of the information that is generated. Transportation demand management, MaaS systems and infrastructure projects would all benefit from detailed, aggregate[2] transportation data including:

- Origin and destination locations
- Trip distance
- Travel speeds
- Regulation compliance
- Time of day
- Number of passengers

This type of data could be used for detailed mobility pricing and incentivizing desired travel behaviours. Health data could alert vehicle or emergency crews to passengers having heart attacks or strokes. Deciding what information must be, can be and should not be collected will require input from privacy experts and law makers.

[2] Reviewing aggregate rather than selected or averaged data can highlight broad patterns without the privacy concerns of accessing individual data.

6.1.4 Privacy & Security Recommendations:

- Encourage the federal and provincial governments to include digital privacy and security standards in the Motor Vehicle Safety Act and Motor Vehicle Act (respectively).
- Avoid excessive data collection and retain only aggregate data.
- Meet or exceed national and provincial privacy and security regulations for any AVs in municipal- or contractor-owned fleets.
- Support companies in Vancouver who are improving AV & V2X data management.
- Follow AV-related privacy and security discussions.

6.2 Ethics and Algorithms

6.2.1 The Ethics of AV Programming

AVs will almost undoubtedly reduce traffic collisions and fatalities caused by human error, as will be discussed later in this report. However, AV technology will likely add additional collisions and incidents due to software errors or equipment failure. Who is responsible when an AV malfunctions and causes damage or injury is still uncertain. Should the user, manufacturer, designer, programmer or infrastructure builder be at fault when all systems are functioning optimally and a fatality, an injury or property damage occurs?

These questions give away to a multitude of other questions about the programming of AVs. Vehicles can be programmed to be aggressive or cautious; to value certain groups (such as children) over others; and to preserve or sacrifice the user. Additionally, AVs will always follow their programming, but should they be allowed to override their programming in an emergency? Questions like this will be especially important during the transitional phase when piloted and driverless cars share the road and other vehicles will not anticipate their movements.

6.2.2 Reducing Risk through Programming & Design

Many companies and researchers are working on solutions to these problems. For example, a Singaporean company NuTonomy is building an AV taxi that will be programmed to violate “low priority” rules such as crossing double lines, when safe, in order to move around double-parked cars (Makroo, 2016). Once researchers and programmers overcome these issues, an AV’s decisions will still be physically limited. It cannot totally predict the outcome of all actions and braking a fast moving vehicle will still take time, so incidents will still occur. Research into this area is still in its infancy (Bonnefon, Shariff & Rahwan, 2015).

The outcomes of these questions are not as important as the way they are decided. It should be the public & experts (through public input, legal and privacy consultation and court cases) rather than companies that makes these decisions. This may result in AV standards that significantly exceed our expectations of human pilots, potentially raising the cost for early AVs (which may make carshare more attractive and an entry point for those interested in AVs) (Fagnant & Kockelman, 2015). This may also challenge vehicle manufacturers to find creative ways to prevent injury, such as Google’s sticky car which protects pedestrians it hits (Titcomb, 2016).

6.2.3 Manufacturer Liability

Insurance companies will also push manufactures to reduce collisions and injury through improved programming and infrastructure. They may also push for manufacturers and designers such as traditional motor vehicle manufacturers, Google or Tesla to be legally at fault for accidents, as they will have a reduced number of entities to seek claims from (Hamilton, 2016). Manufacturers may also create warranties that expire, pushing legal costs back to the owner and encouraging them to purchase a new vehicle. Due to the increased cost of repairing these vehicles, insurance companies are not expecting premiums to fall at the same rate as collisions.

Bonnefon, Shariff & Rahwan (2015) provide three “potentially incompatible” objectives that manufacturers will need to meet (p. 2):

- being consistent;
- not causing public outcry; and
- and not discouraging buyers.

Balancing these needs at a regulatory level is beyond the City of Vancouver’s scope; however, there are still local actions to encourage ethical AVs manufacturing and programming standards.

6.2.4 AV Programming Recommendations:

- Encourage national and international AV programming standards, especially those which will help meet the Transportation 2040 zero traffic fatalities and serious injuries goal.
- Support sustainable & equitable AV programming and design regulations.
- Follow legal, regulatory and ethical discussion related to AVs.

6.3 Large Scale Changes in Employment

6.3.1 Changes to Job Market

As mentioned earlier, AV technology is disruptive and will likely effect individuals with employed in the transportation provision or goods movement industries. Over 500,000 Canadians earn their living driving a vehicle and many more employees support and connect with these drivers (Godsmark, 2015). Some of these jobs may remain, although they may be deskilled to "chaperone" rather than "pilot" positions or require drivers to upgrade their skills to maintain vehicles.

This employee transition could have positive long-term results (with proper safety regulation) as workers will be less likely to be hit by vehicles and they move to safer environments near colleagues.

As noted by Translink, a variety of other fields beyond transportation such as emergency services, collision repairs, driver licensing, traffic enforcement and driver licensing may also see additional job losses (2016). For example, reducing the number and severity of collision-related injuries will reduce the number of medical personnel needed to treat and rehabilitate patients. As these industries transition, government intervention may be needed to mitigate the effect to individual households and unemployment levels.

6.3.2 Government Responsibility

Traditionally, it has been the federal and provincial governments have taken the lead with large scale employment changes. Hopefully, this will include retraining affected workers in the transportation field. Beyond retraining programs, industries should also be encouraged to limit the number of new workers entering the field.

Young workers should instead be encouraged to learn skills that can contribute to new AV-related industries including designing and constructing added-value parts, AV services, and AV software. See section 9.3 for more details on these industries.

For the next generation, new post-secondary programs and grade-school curriculum should include increased coding and engineering skills. In Singapore, the "Developing Computational Thinking as a National Capability" program aims to teach all students basic programming skills, which could stand as a model for Vancouver (Info-communications Development Authority of Singapore, 2016).

6.3.3 Employment Transition Recommendations:

- Encourage the Provincial and Federal governments to research retraining programs.
- Encourage Drivers Services to train drivers in AV maintenance as these vehicles are incorporated into the City's fleet.
- Encourage local AV technology pilots that support the green economy. See section 9.3.5 for additional recommendations.
- Promote programming and engineering education at local schools and post-secondary institutions.

Chapter 7: Infrastructure Impacts & Recommendations

AVs will change the form and function of Vancouver's parking, streets and overall city design. To move Vancouver closer to its long-term goals, foresight and flexibility will be needed to maintain the modal hierarchy and reach long-term planning goals. Rather than look to current conditions, any major projects or developments must consider these changes.

The unique design and capabilities of AVs will likely have a transformative impact on the design of Vancouver's streetscape and city form. Since the exact impacts are impossible to predict and there are currently no case studies available, the following section does include speculative information gathered from academic and industry literature. As AV capabilities evolve, infrastructure and related policies will shape how they contribute to or detract from larger City objectives.

As mentioned earlier in the report, there are two possible infrastructure scenarios based on different models of AV sensing systems (see Table 4).

Table 4
Benefits and Limitations of Different AV Sensory Systems

Type of Sensing System	Operation	Benefits	Limitations
Cloud-based	AVs use information from the cloud to fill in gaps in their sensory systems (cameras, radar, etc.) and moves independently through environment. Likely dominant during transition period. Unable to communicate with driving environment.	• Uses existing infrastructure • Cost effective • Operate in locations without connected infrastructure • Single point of communication with cloud	• Requires access to cloud • Cannot receive local information directly • Missing or damaged signs or markings can create traffic incidents
V2I- & V2V-based	AVs receives information from sensory information and responds to V2X communication to move through environment.	• Can "talk" to users rather than respond to physical movement • Change instructions easily (e.g. changing speeds or access during different times or events) • Change more easily enforce regulations (e.g. speed limits) and implement mobility pricing	• Upgrading expensive • More system entry points increase security risks

Although it is more expensive, V2I- & V2V-based communication could connect the City directly with vehicles and allow for detailed and direct control of speeds, traffic behaviour, and mobility pricing. Infrastructure or street users themselves would be able to request that vehicles slow down around those cycling or walking (forming a travelling *woonerf* or pedestrian street). V2I-capable infrastructure could also request vehicles move to the side of the road, long before the siren of an emergency vehicle is audible.

Currently, manufacturers are working based on one of two models, although the final system will likely be a blend of these two. As sensory systems evolve, regardless of which model is dominant, the City should encourage systems that are responsive to all street users and detailed instructions that change at different times of day.

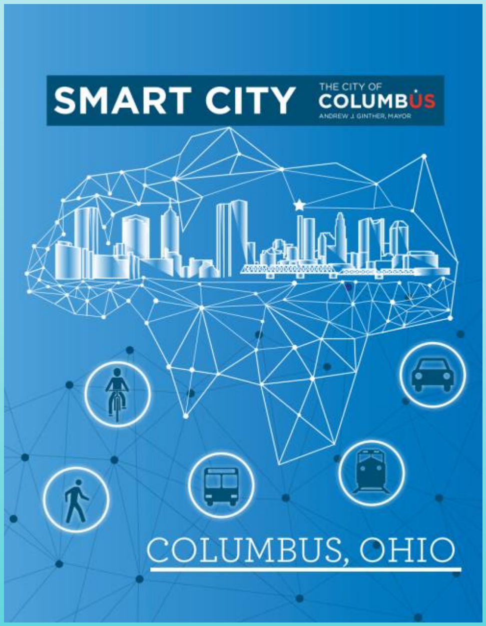

Figure 5: Cover of Smart City Columbus, Ohio Proposal

Case Study: DOT Smart City Challenge

Recently, the U.S. Department of Transportation (DOT) announced that Columbus, Ohio had won the $40 million Smart City Challenge. The funding will fund the integration of “smart” technology (like “self-driving cars, connected vehicles, and smart sensor”) into Columbus’ transportation network (DOT, 2016).

As part of Columbus’ vision statement, the creation of a Smart Corridor was proposed. Automated collision avoidance systems would be installed on transit buses and school buses and self-driving vehicles would be deployed on the corridor. AVs will circle a fixed route to provide transit to underserved residential, commercial and retail areas (City of Columbus, 2015).

7.1 Street-Scale Infrastructure Planning and Policy

Although AVs may use a cloud-based or V2I-based system to interface with their environment, many pieces of infrastructure will require upgrading to maximize the potential benefits of AVs. Unlike today where signage encourages, rather than enforces, compliance, digital infrastructure in the future will provide detailed instructions to AVs. This will include facilitating communication between road users walking or cycling (Anzilotti, 2016).

Case Study: BIG's (Driver)less is More Project

The Bjarke Ingels Group's (BIG) project for the Audi Urban Future Competition proposes a future where vehicles and active transportation users share the same space. Once ACE vehicles eliminate the noise, emission and danger associated with motor vehicles, different transportation modes will no longer need to be separated.

In the BIG future, city streets are transformed into a reactive and programmable surface. AV vehicles travel slowly and are proceeded by digital markers indicating their path. Road users travelling by foot, bicycle or other active transportation mode (and trees) are marked by circles of light (Jordana, 2010). All users will be able to flow along their path and vehicles would slow to a safe speed. In areas of high traffic volumes paths and crossings would materialize and disappear as needed guiding crowds.

Figure 6: A street-level view of project.

Figure 7: Bird's eye view of the project.

7.1.1 Traffic Signals, Traffic Markings & Signage Infrastructure

The next large scale upgrade to traffic signaling & signage infrastructure may be a chance to reimagine its form and function. One such concept is the V-pole ("Vancouver pole") design by Douglas Coupland which imagines poles that provide light, Wi-FI, cell service and EV charging simplifying and combining many different pieces of infrastructure (see Figure 8; Hopper, 2012). The next generation of the V-Pole may be the LinkNYC project (see Case Study: LinkNYC). New infrastructure could even be a micro-generator of power or blend into the trees around it (Burns, 2012).

There also might be significant changes to or the removal of traffic signals, traffic markings and signage designed to communicate with users piloting motor vehicles. Research is already being done on autonomous intersection management (AIM) where an intersection "server" communicates directly with vehicles rather than through traffic lights (Agents Research Group, 2016). AVs would make a request to the server to enter the intersection, receive a response and further instructions from the server (slow down to 40 km/hr, wait 0.1 seconds) then proceed through the intersection. Further research is needed into the level of redundancy required for the safe operation of these signal servers.

In this scenario, those travelling on foot or by bicycle would be able to trigger, perhaps simply by their arrival, a request to the server which would adjust or stop traffic accordingly, so other road users can safely travel through the intersection. Further study into the signalling infrastructure that will best facilitate safe, efficient road movement is needed.

Figure 8: The V-Pole design

7.1.2 Digital Infrastructure

Although it is largely invisible, digital infrastructure will be needed to enable the monitoring of driving environments and the communication with other road users. However, reliable, high speed digital infrastructure will be expensive to construct. Currently, both signalling technology and wireless telecommunications are built on proprietary networks. As many auto manufacturers are already connected to telecommunications companies, this trend may continue. Encouraging open source where possible will encourage digital equity.

Although there are clear benefits if the City were to build this infrastructure itself, the cost for construction and maintenance would be beyond what the City could or should take on. If the City was unable to complete the network, it would essentially render the project worthless until someone was able to complete the project. Rather than completing this infrastructure itself, the City of Vancouver may consider allowing private companies to build this infrastructure like mobile networks or as open source networks.

Case Study: LinkNYC
(New York City, New York)

LinkNYC kiosks were designed by Sidewalk Labs (a Google spin-off company) and have replaced New York's pay phones. They provide public users with free Wi-Fi, video and voice calling, and access to city and emergency services.

Digital, remotely changable advertisements are displayed on the sides of the kiosk which has already generated 500 million in city revenue.

In areas dense with kiosks, a public Wi-Fi network may reduce digital equity in New York. These kiosks may also provide real-time sensory information for Sidewalk Lab's transportation coordination platform FLOW (Sidewalk Labs, 2016).

Figure 9: LinkNYC kiosks in their New York locations, both operating and planned.

The City's real estate and regulatory power creates the leverage to ensure favourable agreements with private companies. The City already owns "dark" unused wire that could be rented or sold. More importantly, it owns the roads and sidewalks that can be sold or leased to private companies. Private companies may offer to provide amenities like Wi-Fi and charging stations for residents like Sidewalk Labs' LinkNYC or Shaw Go Wi-Fi in exchange for space to build their infrastructure networks (See Case Study: LinkNYC). For LinkNYC, which is already operating, the cost to provide these services is relatively cheap compared to what they receive in return, the ability to monitor the environment and connect with customers, AVs and a variety of devices.

7.1.3 Changes to Minor Street Design

AVs have two abilities that may change the design and use of minor streets. First, AVs are self-parking which could will reduce or eliminate the need for on-street parking. Any changes in parking location must be weighed against a possible increase in **Vehicle Kilometers Travelled** (VKT). Encouraging SAV use would likely reduce VKT travelled searching for parking and reduce the space needed for parking.

Second, AVs are able to use narrower right of ways (and potentially have a smaller vehicle footprint). This may reduce the space needed for vehicles to drive and return vehicle street space to other road users. This space on minor streets could be used for more street furniture, extended sidewalks and curbs and designated cycle paths.

Minor streets could even be redesigned for slower vehicle speeds or exclude motor vehicle traffic. Designated AVs could still transport young children, seniors and those with disabilities to directly to their residence and provide emergency assistance. Designated pick-up and drop-off spots would be used by the majority of residents. Mannheim, Germany and Oslo, Norway are already considering removing vehicles from neighbourhoods or the city centre as part of AV initiatives (See Case Study: Car-free Neighbourhood. Peters, 2016; Agence France-Presse, 2015).

Even making these types of changes, on some streets or only east-west sections of blocks, could reduce doorings and conflicts at intersections. This could eliminate injury risks for those travelling by bike (Urban Systems and Cycling in Cities, 2015). AVs on minor streets could also be programmed to drive at slower speeds creating flexible *wonnerf* streets with minimal changes to hard infrastructure.

Case Study: Car-free Neighbourhood
(Mannheim, Germany)

Many cities in Europe and Asia have significant car-free or car-light zones, with cars parked in shared spaces at the community edge.

In this German concept, the neighbourhood streets are car-free, and vehicles are stored in shared parking space under the streets. Active transportation pathways connect the entire neighbourhood and a tram line connects the neighbourhood to the city (Peters, 2016; Murgia, 2016).

Houten, Netherlands provides a similar example at a larger scale. In this community, residents through foot and cycle paths at the centre and keeping cars to the city’s edge.

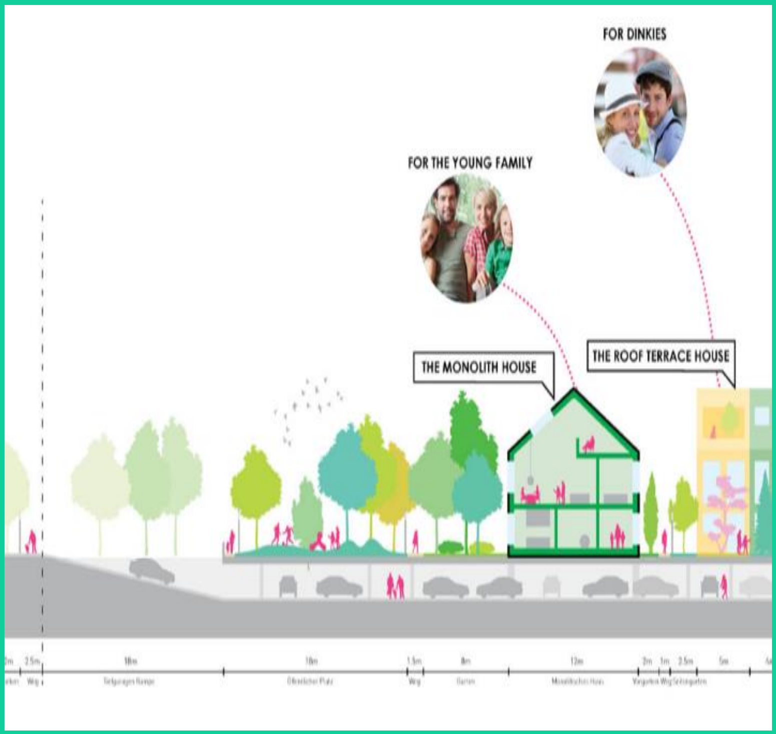

Figure 10: A cross-section of Mannheim's car-free neighbourhood.

7.1.4 Changes to Major Streets & Intersections

Although AVs can operate on streets as they are, their capabilities can be maximized through changes to the design of major streets and infrastructure. If AVs are able to reduce the space between vehicles in a lane, Isaac (2016) estimates that with 90% AV market share, freeway congestion would be reduced to 60% of its current levels. Additionally, if AVs can drive in narrower lanes, road space can be reallocated for walking, cycling and transit paths.[3]

At intersections, traffic signals and signage for vehicles could be removed and replaced by servers that would maintain steady flows of traffic with minimal stopping. Smart programming would be able to prioritize SAVs and emergency vehicles at intersections (Isaac, 2016). These improvements could reduce stopping time at intersections further reducing congestion and fuel consumption. However, any new intersection designs must be able to maintain cycling and walking flows.

[3] As electrical charging technology improves, designated lanes could charge vehicles, including electrical buses, although this technology may be prohibitively expensive (Gil & Taiber, 2013).

7.1.5 Recommendations for Street-Scale Infrastructure Policy:

- Design streets and intersections that prioritize walking, cycling, and transit users.
- Future proof any upgrades to electronic signaling infrastructure.
- Support a shared AV approach that reduces the total number of vehicles on the road, through measures such as comprehensive mobility pricing.
- As the total number of motor vehicles decline and on-street parking becomes obsolete, convert road space towards people-friendly pick-up/drop-off mixing zones, improved walking and cycling infrastructure, mass transit, enhanced public space, and other civic priorities.
- Explore how AV technology and connected V2X infrastructure could ensure location- and time-base traffic rules and regulations with 100% compliance, including speed limits and access restrictions.
- Consider implementing street hierarchies or zones within the city and region where different types of vehicles are and aren't allowed, e.g. AVs versus non-AVs, non-motorized zones with limited exceptions, etc.

7.2 Parking Planning and Policy

As mentioned in the previous section, AV technology will significantly impact parking needs, in terms of both supply and demand. Currently, vehicle users prefer to park near their destination and the form of North American cities is oriented towards this preference. For every privately owned car, spaces are required not just at home but at numerous destinations across the city on streets, in parking lots, and in parkades. The time and VKT spent searching for parking also has a significant impact on congestion in the city; some researchers estimate 30% of city traffic can be attributed to people searching for parking (Isaac, 2015).

If AVs are able to transport themselves to a parking location, the amount of parking can be reduced and unbundled from the destination location, improving affordability for residents and business. The area of parking could be further reduced through automated parking services that store and fuel AVs in tightly packed locations.

Figure 11: A transfer station and underground parking storage for Munich's automated parking.

Case Study: Automated Parking
(Munich, Germany)

At Donnersbergerstraße, 284 cars are stored compactly by an automated parking system. Only 4 parking transfer stations are visible and can accommodate families, seniors and persons with disabilities (GIVT, 2016).

The parking is more secure than on-street parking and has additional environmental benefits. This system reduces energy expended searching for and maneuvering into parking stalls.

7.2.1 Parking for Private and Shared Autonomous Vehicles

These changes in parking behaviour require design and planning responses that prevent excessive VKT and utilize newly available space. Without changes to the transportation and parking systems, AV owners may send their vehicles long distances to find free parking, potentially return all the way home or even circling until they are ready or pickup. If this behaviour becomes common, it will significantly increase energy use, VKT and congestion.

However, if the transportation system is reoriented to focus on mass transit and SAVs, the City would be able benefit from these changes by reallocating parking spaces. However, researchers have come to different conclusions about the amount of space that will be available. In a gridded city (like Vancouver), Fagnant & Kockelman (2014) estimate that each SAV will remove the need for 11 parking spots in the city. Isaac (2015) estimates a more conservative 8 spots will be removed, but proposes that SAV fleets will completely remove the need for on-street parking and reduce off-street parking by 80%. Whatever the amount, research does indicate a significant amount of parking space will be available for reallocation.

For private and shared vehicles, the City should consider implementing anti-deadhead mobility pricing which charges owners when vehicles travel without a passenger. Parking costs will need to find a balance, expensive enough to encourage SAV use and being inexpensive enough to discourage long trips to find “free” parking. Mobility pricing could also contribute by charging owners when their vehicle travels without a passenger.

7.2.2 Changes to Parking Distribution

These new parking behaviours could change the use and distribution of parking space in the city. As noted earlier, on-street parking could be reallocated towards walking, cycling, transit, and other uses. Larger surface lots could become housing, community space, etcetera or be used by SAV fleets.

Reallocated road space could also support the Greenest City goal to increase resident access to nature by opening significant amounts greyfield space for conversion to green space (City of Vancouver, 2015a). Some underground parking and parkades could also be used by shared SAV fleets or individual owners for charging and servicing, while others could be converted into industrial space. Freed parking space represents a unique opportunity for infill and conversion that is unlikely to occur again (see Figure 12).

Rather than using surface parking, AVs could park and charge in less desirable locations underground or outside the core. However, trips outside the core should be minimized to conserve VKT and energy (and prevented wasting energy driving to and from charging locations). Less desirable locations include locations that cannot be easily converted to other uses such as parkades and underground parking garages. This may include transitioning private residential and business parking into publically accessible-spaces (or at least accessible to AV maintenance workers). These changes in distribution will effectively separate parking from origin and destination.

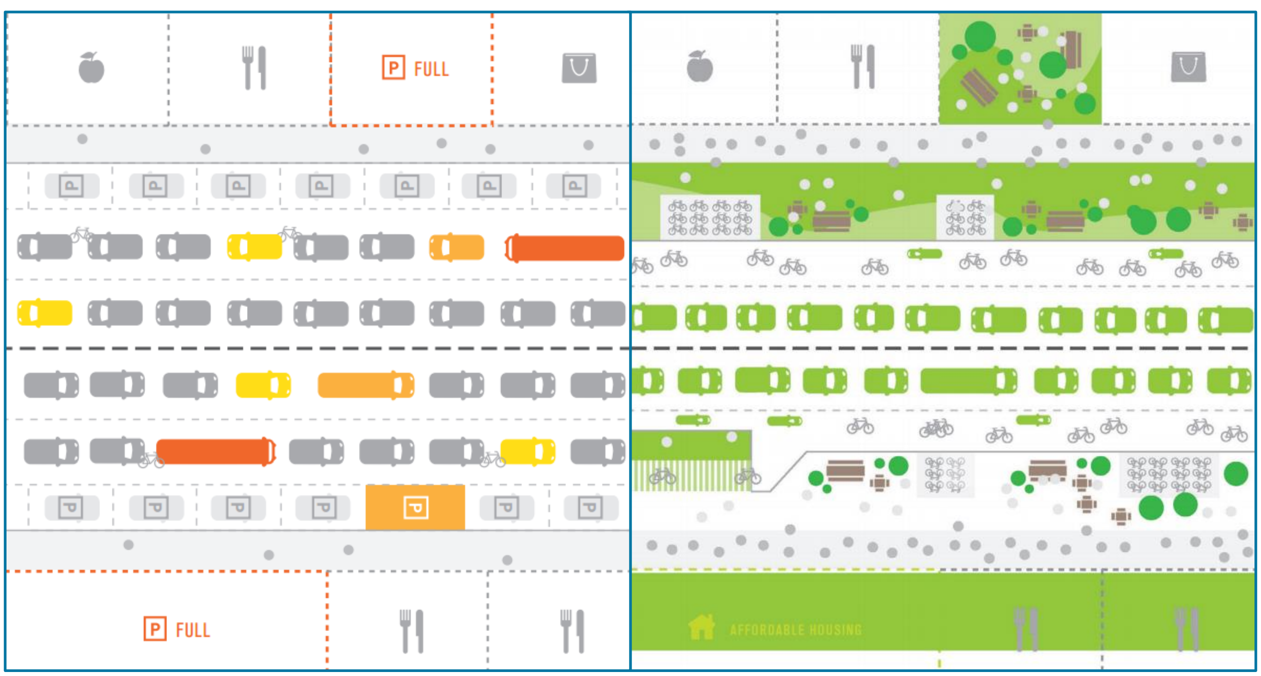

Figure 12:From San Francisco's Smart City proposal, a comparison between a status quo future (left) and a ACES future with road and parking space reallocated to other uses (right).

7.2.3 Future Proofing Parking in Developments

To maximize the potential future benefits of AVs, reduced parking minimums for developments and flexible, sharable parking should be built into current building codes. Rather than constructing new automated parking locations, converting current parking structures should be retrofitted to take advantage of this technology. Parking spaces that cannot be retrofitted could be converted to other uses (see Figure 13). Current policies to reduce parking minimums in exchange for car share spaces and heritage retention should be encouraged and expanded.

These types of changes will significantly impact municipal costs and revenues. Fewer parking spots will also reduce maintenance and monitoring costs (a $15,153,000 expense for the City in 2015) and also reduce the revenue generated from parking ($53,178,000 revenue in 2015, around 4% of total revenue). Eventually, parking monitoring may even be automated and conducted by street infrastructure which could further change parking expenditures (Budds, 2016). This reduction in expenditures and revenue should be considered, along with the other parking technology and employment concerns, as part of larger changes to the design and planning of the city.

Figure 13: TIPSLab Conceptual Renderings of the Parkades of the Future

7.2.4 Recommendations for Parking Policy and Planning:

- Require parking in new developments to be shareable by non-residents and non-tenants. In the short-term, this supports the unbundling of parking, positively impacting housing affordability. In the long-term, this enables utilization of the space by shared vehicles, supporting a shared autonomous vehicle rather than private autonomous vehicle model.
- Develop a retrofit program to make it easier to share parking in existing buildings.
- Design parking to be adaptable to other uses, considering that future parking requirements will be greatly reduced.
- Consider where future shared parking and charging locations are located, how they are managed, and how these decisions can impact VKT and travel behaviour.
- Continue reducing parking minimums for developments, renovations and infill.
- Create mobility pricing and parking fee structures which will encourage shared autonomous vehicle use and discourage lengthy deadhead trips to find “free” parking.
- Encourage a shared, rather than privately-owned, AV model to reduce parking space and free land for other uses.
- Identify on- and off-street parking that could be converted to other uses that fit long-term planning goals.

7.3 City-Scale Design Planning and Policy

7.3.1 Congestion Reduction

Road congestion costs the Metro Vancouver region upwards of 1.2 billion dollars annually (Dachis, 2015). Currently, AVs are being promoted as one possible solution to road congestion in urban areas.

According to Le Vine, Zolfaghari & Polak (2015), because AVs are able to anticipate and react to the movement of other vehicles, they will likely reduce congestion as they can be programmed for more consistent speeds, smoother breaking and shorter headways between vehicles at the micro-scale.

On the macro-scale, Fagnant & Kockelman (2015) found AVs may if reduce congestion if they can navigate intersections without stopping, determine optimal traffic routes, form platoons and spend less time searching for parking. Connected infrastructure may even be able to manage the city as a whole system, rather than intersection by intersection which could further reduce congestion. Any reduction in the number of collisions will also reduce congestion, perhaps rendering morning traffic reports obsolete.

7.3.2 Challenges to Congestion Reduction

AV congestion reduction claims are overstated for several reasons:

Firstly, as noted elsewhere in this report, AVs could increase VKT, either by making longer trips more attractive and creating deadheading trips where AVs do not have passengers (Fagnant & Kockelman, 2014).[4]

Secondly, much of the literature assumes that AVs in the same lane will drive much more closely together than piloted vehicles. However, there is a relationship between what users will tolerate and desire from the rate of acceleration and deceleration, especially considering they may be reading or resting (Le Vine et al., 2015). Assuming that passengers will prefer speeds similar to train or LRT travel in order to work on tasks, the researchers suggested that AVs may need more headway to avoid a "jerk" during stopping and starting, unless they are able to communicate with vehicles in front of them (which may be possible towards the end of the transition to AVs).

Since an uncomfortable trip runs counter to AV aims to free trip time for work, leisure or rest, users may require or program a more comfortable trip. If individual users are able to control the level of acceleration and deceleration, they may decide to decrease acceleration and deceleration rates even further with only minor increases to trip length. At the city scale, this could create a tragedy of the commons scenario: Individual passengers are not inconvenienced by their choices, but all users are inconvenienced by every individual decision who chooses slower acceleration speeds. This modelling does not take platooning and cooperative behaviour into account. More detailed, varied and real-world testing is needed.

The ease of AV travel may also encourage residents to choose motor vehicle trips over active transportation trips.

The ease of AV travel, especially if users choose single-occupancy over multi-occupancy motor vehicles, may also encourage residents to choose motor vehicle trips over active transportation trips. Rather than focusing on removing congestion, congestion should be used to encourage residents to travel by foot or bike on shorter trips. This can be done by setting traffic speeds which increase safety and make walking and cycling more time-efficient options. Slower speeds can also make streets safer for all road users (National Association of City Transportation Officials [NACTO], 2016).

Although reducing congestion is beneficial to the economy, it may have unintended effects such as inducing further travel, increasing VKT or reducing the number of cycling and walking trips. This effect could be mitigated through comprehensive mobility pricing, a key strategy noted elsewhere in this report.

[4] Fagnant & Kockelman (2014) estimate an 11% increase in VKT.

7.3.3 City Design & Land Use

AVs could influence land use in a number of ways:

- On one hand, they may encourage infill and densification by reducing the need for parking.
- On the other hand, without strong land use and mobility pricing policies, they will significantly encourage sprawl by making long commutes more attractive; the perceived cost of commuting is significantly less if people can use the time in their car for work or family, or simply sleep.

Once AVs are introduced, urban areas could see an increase in density around core areas as well as sprawl around the edges, potentially drawing areas outside the Agricultural Land Reserve (ALR) into the region. Metro Vancouver, for example, may densify as surface parking lots and parking garages are removed, potentially opening new lots across the city, perhaps the last chance for large-scale infill. At the street-scale, additional lane-way housing and garage conversions may occur, as households shed their privately-owned vehicles. Since workers may be able to do most of their work in their vehicle, business may also shed space to reduce overhead, rent and property tax potentially densifying commercial and industrial areas as well (Vass, 2016).

If the city does densify and private car ownership continues at high rates, additional electrical infrastructure will be needed to maintain charging levels. Workplaces will need the capacity to charge their employees' vehicles during the work day. SAV may be the best way to mitigate these needs.

Case Study: City Wide AV Testing Area
(Wuhu, China)

The City of Wuhu, in partnership with the China's Ministry of Housing and Development, has granted permission for technology firm Baidu to test AV vehicles within city limits. The project will have two phases, first buses and cars will be tested for three years in restricted areas. After that, test areas will be expanded and the technology will be commercialized for residents. Although it is not clear, the pilot seems to be aimed at replacing private vehicles with shared autonomous vehicles (BBC, 2016). China has recently banned highway testing of AVs so cities like Wuhu may be the only place to test AVs in China (Bloomberg News, 2016).

Figure 14: Baidu's AV being tested in Wuhu.

A MaaS-based transportation system that encourages mass transit may also encourage density around transit-oriented developments (TODs). However, a successful MaaS system's ability to solve the **first and last mile problem** may make areas at the edge of the region more accessible to transit and may reduce the pull to areas of high density (Godsmark et al., 2015). MaaS transportation will require flexibility to adjust in order to maximize its benefits and prevent excess sprawl.

Strong land use and mobility pricing measures are critical to offset these pressures. Mobility pricing can discourage longer trips and encourage higher vehicle occupancy. Land use measures can be put in place to discourage or prevent sprawling, auto-oriented development, and encourage infill rather than greenfield development

Without such measures, commuters will be able to jump over the Agricultural Land Reserve's urban containment boundary and reside in Chilliwack, Hope or even Kamloops where housing prices are cheaper. This could cause the urban core to "empty out" (as it did during the introduction of the automobile) depressing Vancouver land values and undoing decades of work. The City's current layout was not created passively; it is the result of deliberate policy, regulation and community activism. As AVs become a key part of urban mobility, strong measures will need to be in place to ensure compact communities that are walkable, bikeable, and oriented around mass transit.

7.3.4 Future Proofing Major Projects

As noted earlier, AVs will likely change the land use patterns and transportation systems in Vancouver and the surrounding region. Projects like the Massey Tunnel Replacement and other major infrastructure need to be evaluated against this future. To prepare, the Conference Board of Canada (Godsmark, 2015) recommends that large infrastructure projects undergo a **future proofing** audit. Projects should be tested against projections and models that include AVs.

Since most large infrastructures projects have a 30- to 50-year lifespan and nearly full integration of AVs is expected in the most 10 to 25 years, these types of audits should be considered a necessity. The Canadian Environmental Assessment Act 2012 requires environmental impacts be avoided unless justified and may results in challenges to future infrastructure projects who have not considered AVs in their projections (Transportation Benefit-Cost Analysis, n.d.). In order to conduct these audits, traffic forecasting models will be needed to capture new mobility patterns.

In addition to audits, updated regulations, standards, codes and geometric design will also be needed. These are not considerations that can be delayed until AVs are already integrated.

7.3.5 Recommendations for City-Scale Infrastructure

- Develop coordinated regional and provincial responses to AV technology which support compact sustainable urban development and discourage auto-oriented sprawl.
- Develop a comprehensive regional mobility pricing strategy that prioritizes active transportation and mass transit, and that is sensitive to travel time, congestion levels, and vehicle occupancy rates.
- Create AV policies that support Metro Vancouver regional growth strategy goals by encouraging compact, complete communities; protecting rural, agricultural and natural lands; and supporting sustainable transportation and transit-oriented development.
- Anticipate significant changes to traffic patterns and pressure on the urban containment boundary.
- Set AV traffic speeds which:
    - Encourage residents to walk, cycle and use transit for shorter trips,
    - Respond to nearby road users, including those cycling,
    - Discourage sprawl by maintaining current highway speeds.
- Rather than invest in costly projects to expand road capacity, like the Massey Tunnel Replacement Project, implement a future proof audit system for all major infrastructure projects.

Chapter 8: Transportation Impacts and Recommendations

"By 2040, we envision a city with a smart and efficient transportation system that supports a thriving economy while increasing affordability; healthy citizens who are mobile in a safe, accessible, and vibrant city; and a city that enhances its natural environment to ensure a healthy future for its citizens and the planet." (Transportation 2040, 2012)

To meet the Transportation 2040 goals after AVs are introduced the City must continue to strengthen policy and take action to support a compact, walkable, transit-friendly Vancouver.

8.1 Walking Network

Walking must remain at the top of the modal hierarchy and autonomous vehicles must respond and react to all dimensions of pedestrian actions. Design decisions should support these goals, which may even mean restricting AVs and other motor vehicles from different areas of the city. The reduction of parking and road space needed for AVs creates space that can be used to upgrade walkways and public spaces.

To make walking safe, convenient, comfortable, and delightful as directed under Transportation 2040, AV transportation should encourage walking. AVs must respond to a variety of walking behaviours, including those walking who travel at a slower pace or use mobility aids, at different times and in different weathers. As AVs are introduced to Vancouver, they may become so convenient, they discourage walking, cycling, and transit. This could be exacerbated if AVs encourage more sprawling auto-oriented development that make active transportation difficult. Design responses to AVs that prioritize active transportation are described in section 7.1 and include widening sidewalks or adding green space. Whether these changes are done piecemeal or as part of infrastructure changes, the introduction of AVs could benefit the walking network.

8.2 Cycling & Other Active Transportation Modes Network

Like the walking network, the cycling network must be maintained and strengthened when AVs are introduced to Vancouver. To increase safety, AVs must be able to respond to the typical and atypical active transportation behaviours. Since AVs will likely need less road space, there may be additional space for cycling and other active transportation modes on roadways.

In Vancouver, cycling, skate boarding and other form of active transportation should continue to be prioritized over AVs and motor traffic. Currently, AV programming cannot predict and understand common bicycle movements such as a track stand (gently rocking to maintain balance at a stop) (Reid, 2016). Thus, some AV manufacturers are framing cycling as an obstacle to AV integration and have suggested the full separation of AVs and bikes. Rather than support this, the City must communicate that if AVs cannot accommodate active transportation users, then it is AVs who will not be allowed on public roadways.

Case Study: MaaS Transportation Replacing Personal Vehicles
(Helsinki, Finland)

In Helsinki, the government plans to remove private vehicles from the city by creating a MaaS ecosystem. Rather than banning cars, the MaaS will allow users to purchase the mobility they need, whether that is vehicle or transit travel. Through this public utility, they will pay per kilometer or buy a package of kilometers on a suite of transportation modes. Any company will be able to provide a "mobility on demand" service through a single app (Aalto, 2014).

The Helsinki Regional Transportation Authority has already created a minibus called Kutsuplus which can determine the optimal route for all its passengers. Although it is still manually driven, this technology could be used to solve the last mile problem once AV technology is introduced (Greenfield, 2014).

There are two major barriers to implementing this system across Finland. First, not all residents own a smart phone. Second, other Finnish cities may not have the density needed to support a complete MaaS ecosystem (Greenfield, 2014).

Figure 15: A conceptual design of a MaaS-supported Helsinki.

Once AVs can respond appropriately to bicycle users, these vehicles will likely be safer and more predictable than manually driven vehicles. According to Fagnant and Kockelman (2015), although vehicle collisions will likely decrease by 80% or more, incidents between motor vehicles and active transportation users will see only half of this benefit because only half of the parties involved will be using AV technology. However, this assumes that vehicles and active transportation users are equally likely to be a fault in an incident. As the Cycling Safety Study (Urban Systems & Cycling in Cities, 2015) shows those travelling by bicycle had right of way in 93% of incidents with vehicles, so there may be a greater reduction than Fagmant and Kockelman expect. Further researcher and monitoring is needed.

8.3 Transit Network

The transit network will be the transportation system in Vancouver most affected by the introduction of AVs. Depending on policy decisions, AVs could either undermine the transit network or be a flexible solution to the last mile problem. Maintaining a high-capacity transit network that supports compact, complete, and active transportation-oriented communities will require strong policy and programs, such as mobility pricing and MaaS.

With effective policies in place, SAVs could help make the transit system more efficient. Specifically, they could potentially replace low-performing suburban transit routes and local last-mile transit services. New shared AV services could be operated by conventional public transit operators, or by companies such as Tesla or Uber. Public transit agencies should think carefully about who should manage such systems, and how different operators might work together.

Some AV advocates argue that AV technology could replace transit altogether and have suggested directing funding away from public transit and towards AV technology. This should be viewed with concern. When designed well and coordinated with appropriate land use, rapid transit remains the best way to move large numbers of people. Unlike AVs, rapid mass transit encourages and complements land use patterns that are compact, supporting the preservation of agricultural land and natural habitat, and encouraging healthy active transportation choices for short intra-community trips. If AVs supplant rapid transit, there is a higher risk that this technology could exacerbate the sprawling, auto-oriented developments that consume more land and discourage short walking and biking trips.

8.3.1 AV Transit Scenarios

AV technology could create three different transit scenarios:

1. **Personal Rapid Transit Scenario**: Small vehicles, privately owned or shared, would transport the majority of road users directly from their origin to destination.

   This personal rapid transit (PRT) would likely increase congestion and social isolation while reducing active transportation trips. Although PRT is more convenient, it would likely be provided at higher cost. The transit system would be reduced and provide infrequent service to only those who were unable to purchase the added convenience. Since there is a finite amount of road space, this system is likely less efficient and will push Vancouver further away from its mode share goals and the Greenest City Scenario.

2. **Extended Transit Scenario**: Mass Transit and buses will continue to provide service along high-volume routes, especially at peak times, supplemented by smaller multi-occupancy vehicles.

   According to the Conference Board of Canada, traditional mass transit will remain “the most efficient way to move a lot of people very quickly” on “existing high-volume transit routes during peak periods” (Godsmark et al., 2015, p. 42). Smaller AV shuttles and vehicles can support mass transit by providing responsive, reliable and timely service to low-density areas, especially outside of peak times, and solve the first and last mile problem. This is all provided as a single service through a MaaS interface.

3. **Mixed Scenario**: A mix of the two scenarios above.

The mixed scenario is the most likely because scenario 1 & 2 because different users will have different (and evolving needs). For example, families with multiple young children, may find they value the convenience of storing belongings in their privately-owned vehicle in spite of any financial disincentives. However, it is still in their best interest to have AV-support transit, as reduced less congestion, emissions and overall VKT overall are a benefit to all.

8.4 CarShare, Taxis & Rideshare Networks

Shared Autonomous Vehicles (SAVs) build upon the carsharing networks of today, and could play a large role in future transportation systems. Users would be able to request pick-up when needed, wherever they are. SAVs could complement a mass public transit by providing reliable, cost-effective service outside of peak hours and in low demand areas, solving the first and last mile problem. This would encourage users to shed personal vehicles freeing parking space and, with effective mobility pricing and street design, encouraging walking and cycling for shorter trips.

Traditional carshare in Vancouver is provided by four carriers (car2go, Evo, Modo and ZipCar) and has grown rapidly in the past two years, doubling both memberships and vehicles. Member surveys and other research suggest that carsharing is an effective way to reduce the number of privately owned vehicles on the street. For example, a recent study concluded that for every car2go vehicle on Vancouver's streets, members sold an average of two cars and avoided purchasing 7 others – in other words for every car2go in Vancouver, there are nine fewer privately owned vehicles (Metro Vancouver, 2014; Martin & Shaheen, 2016).[5] The same study indicated a significant reduction in VKT and greenhouse gas emissions (Martin & Shaheen, 2016).

Figure 16: A nuTonomy taxi prototype.

Case Study: Autonomous Taxi (Singapore)

In Singapore, nuTonomy is piloting its Autonomous Taxi on a tech park and will gradually extend its area of travel to urban Singapore. Using a smart phone, travelers select their location and destination, then an AV travels to them for pick up, although they are currently only able to request pickup from predetermined locations.

This technology uses formal logic to give vehicles the rules of the road and tell them when they can violate them in a safe and reliable manner, such as driving around a double-parked vehicle. NuTonomy believes that AV will enter the market as shared vehicles since corporations and governments are better able to absorb the high costs of the sensors and computers, especially when compared to the cost of a driver (Ackerman, 2016).

Singapore is attracting this type of technology because the government is proactive and flexible. Other companies are also testing vehicles there like 2getthere Asia which has created GRT pods for the first and last mile problem. They can seat 8-12 people sitting or 24 people standing (Robarts, 2016).

[5] Metro Vancouver found 5 to 11 vehicles were shed or never acquired for every carshare vehicle (p. 23, Metro Vancouver, 2014). Martin & Shaheen (2016) found car2go members shed or delayed acquiring 9 private vehicles for every car2go vehicle available in their city.

It is very likely that AVs will make the biggest market inroads as part of shared fleets, particularly in cities like Vancouver where carsharing is very successful and other transportation options are attractive for many people. Many manufacturers are already expecting AVs to be sold as fleets to companies rather than individual owners and companies like Uber are working on developing their own vehicles (Godsmark et al., 2015; Martinez-Barberá & Herrero-Pérez, 2016).

SAVs will likely to best way to introduce residents of B.C. to AVs as they are interested in the technology but more than half are unlikely to buy a self-driving car (Mackin, 2016). Eventually, SAVs may merge a variety of services such as carshare, rideshare (e.g. Uber), taxis, carpooling and peer-to-peer carsharing services.

SAVs will also be able to replace low-performing bus and shuttle routes while increasing flexibility for those needing services. They can offer the right-time, right-size vehicle that allows users to choose mass transit services when and where they are available. This may include different tiers of SAVs appealing to a variety of users. Connecting users with SAVs through MaaS could complement, rather than replace traditional mass transit.

While a future where most AVs are shared rather than privately owned is preferable, there are still negative impacts that need to be addressed to move towards a Green Mobility future (see Table 5).

Table 5
The Potential Positive and Negative Effects of SAVs in Vancouver

Positives	Negatives
• Reduce private car ownership and parking spaces (Fagnant & Kockelman, 2014; International Transport Forum [ITF], 2015) • Reduce CO^2 emissions (Fagnant & Kockelman, 2014; Martin & Shaheen, 2016) • Encourage switch to EV technology away from fossil fuels (Godsmark et al., 2015) • Speed switch to more efficient EV technology due to compressed lifespan of shared fleets (Fagnant & Kockelman, 2014) • Increase the number of multi-occupany trips (ITF, 2015).	• Increase VKT from deadhead trips between users (ITF, 2015). • Decrease mass transit use • Decrease transit accessibility for low-income households

8.4.1 Integrating MaaS & SAVs

Many of the negative effects of SAVs can be mitigated with mobility pricing that encourages walking, cycling and mass transit. Additionally, although private companies may provide SAV services through MaaS, public agencies will still need to regulate and possibly operate some SAV services to ensure the system is accessible to low-income users and those living farther from mass transit. Ideally, the cost of providing service to these users would be subsidized by users who choose “luxury” vehicles either directly through MaaS or through associated mobility pricing. However, to prevent sprawl, difficult questions will need to be answered about how much subsidization is acceptable, especially for users live away from transit centres.

8.4.2 Carpooling & Informal CarShare

Although fleet-based services will likely be the dominant form of SAVs, some users could own and rent a personal vehicle (or seats in a personal vehicle) through a private service (similar to the AirBnB concept) (Jaynes, 2016). This type of peer-to-peer carsharing is already legally allowed in B.C., with appropriate insurance (Metro Vancouver, 2014). Tentative support may be appropriate as it could still supplement the transit system, reduce vehicle ownership and increase vehicle occupancy. More research will be needed on how this will affect VKT and emissions. Uberpool and Bridj are already exploring software to support these types of services.

8.5 Personal Vehicle Ownership

Personally owned vehicles may no longer be needed in the autonomous future, although some people may still choose to own their own vehicle. The City should encourage those who do own to purchase low-emission vehicles and prevent unnecessary trips with mobility pricing.

In Canada, the average private vehicle sits idle for over 23 hours per day and costs over $9,000 annually if driven regularly (ITF, 2015; CAA, n.d.; IBI Group, n.d.). Initial research indicates that switching to SAVs could save individual households an average of $2,700 per year (4% of the average household budget) by decreasing insurance, fuel and parking costs (Godsmark et al., 2015; Fagnant & Kockelman, 2015). However, even if AVs technology increases the cost of vehicles, individuals may pay more to purchase a vehicle.

Residents of Vancouver should be able to choose transportation fitting their budget and needs, including those who own a personal vehicle. Some, such as large families or independent contractors, may choose to own a vehicle regardless of time or cost incentives or disincentives. Rather than use significant resources to reach these groups, the City should focus on reducing ownership by creating a resilient and flexible transportation system.

Unless ownership is reduced when AVs are introduced, congestion, fuel use and VKT may still increase as owners may request vehicles circle or drive long distances to find parking, perhaps even returning to their personal residences. To prevent this type of behaviour, CV technology will allow mobility pricing to easily be applied to personal vehicle and should be as sensitive as pricing on a MaaS system to travel times and vehicle occupancy (to discourage deadheading trips).

8.6 Goods, Services and Emergency Response Movement

From port to rail to store to household, the movement of goods and services in Vancouver is vital to the city's economy. Service vehicles of all sizes must be able to travel safely on the roads. AVs technology should be used to improve the transportation of good and services as well as the emergency response vehicles.

Service and emergency response vehicles will likely be the last vehicles to be automated due to their complex driving environment. For ground level goods movement (77% of ground transportation in Canada) there are three types of movement to consider which present different opportunities and challenges as outlined in Table 6 (Government of Canada, 2016). Some of the greatest uncertainties related to AV goods movement may be if there will be any changes to the distribution and size of stores if companies move towards a home delivery model of service rather than an in-store purchase model.

Table 6
Challenges & Opportunities for AV Goods Movement

Type of Movement	Opportunities	Challenges	Uncertainties
All types of goods movement	• Reduce delivery cost • Reduce labour costs	• Unemployment • Reduced pay for remaining positions	• Change in cost of goods • Changes to distribution and size of stores
Producer to supplier to store (freight)	• Reduce driver stress • Reduce fatigue-related accidents • Increase travel speeds • Reduce vehicle wear and tear	• Reduce active transportation and compact communities by building larger distribution centres rather than stores	• Change in fuel source
Store to household (neighbourhood delivery)	• Reduce household time spent purchasing goods • Reduce cost of space • Reduce road space needed with efficient delivery routes	• Reduce social networks and connection to place • Spread distribution locations increasing VKT for those seeking in-person assistance • Loss of anchor grocery stores in transportation oriented developments	• Cost of small deliveries

Emergency services will likely benefit the most from autonomous vehicles on the road. Connected infrastructure and AVs can work together to move vehicles quickly off the road and provide a space for emergency vehicles to travel at top speed. Responders can also use this time to set up equipment and speak via phone with 911 staff and those on the scene to better assess the situation before arriving. Emergency vehicles may need backup power systems and manual override controls so responders can take these over if necessary if electrical power or networks are not running.

8.7 Retrofitting & Transition

Many of the purported benefits of AVs require most or all vehicles on the road to be automated. There will be a transition period where AVs mix with conventional manually-operated vehicles potentially creating additional problems.

A future where autonomous vehicles are the primary mode of transportation given the potential to reduce traffic fatalities and serious injuries. However, the transition period where piloted and automated vehicles interact may involve increased traffic incidents and policy dilemmas. Consequently, many hours of driving modeling and real-world driving must be recorded before AVs are allowed on to streets. They must also be responsive to typical and atypical active transportation movements.

As the transition moves forward City Council should continuously reflect on the policies they create and how they are affected transportation and land use within the city. Progressive policies may even include barring vehicles with ADAS from streets as drivers has been shown to be less attentive when using these systems (NACTO, 2016).

In the following timeline, the steps to an automated transportation system are laid out. The steps in this timeline may occur in a different order and some may never occur, however the trend toward automation will likely continue. The likelihood of each step will be directly affected by national, provincial, regional and local policy and regulations.

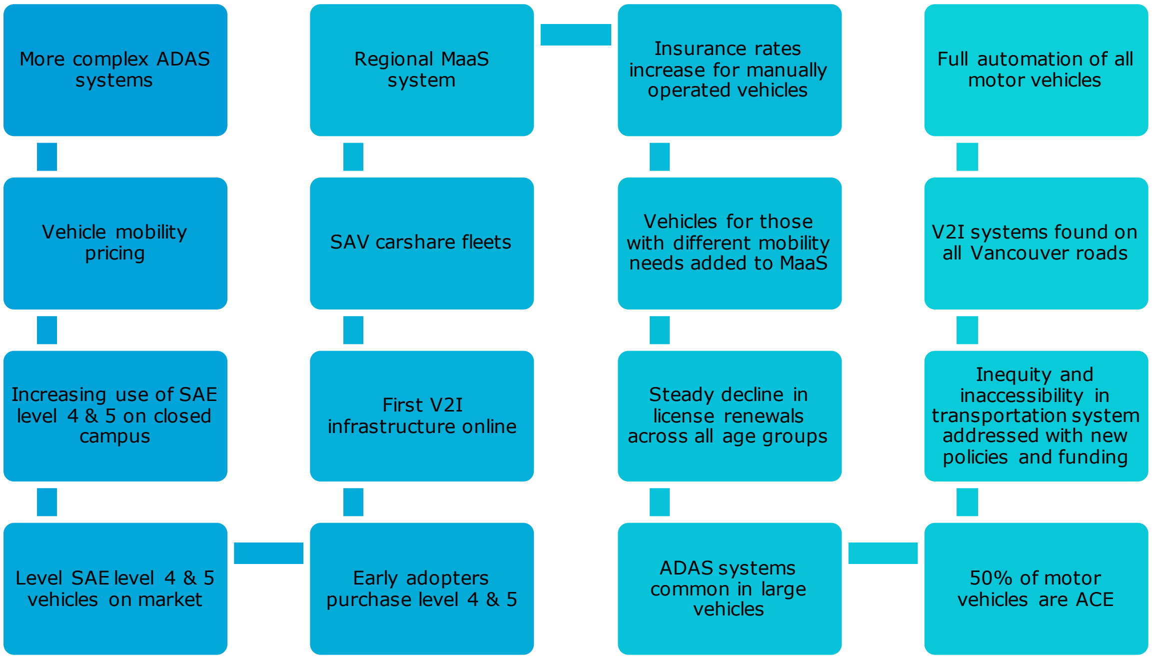

Figure 17: A potential timeline for AV introduction in Vancouver

AV technology (and other technologies such as MaaS) may also create financial and structural barriers for low-income individuals, families and those without personal digital devices. Subsidies and creative interventions will be needed to maintain an accessible and equitable transportation network.

8.8 Transportation System Recommendations

- Support autonomous vehicles, shared autonomous vehicles & Mobility as a Service technology that will:
    - Improve rapid transit and local transit;
    - Improve transit reliability and equity;
    - Address transit network gaps;
    - Reduce dependence on personal vehicle ownership;
    - Reduce Vehicle Kilometres Travelled, emissions and congestion; and
    - Return commute and errand time to individuals.

- Implement mobility pricing across all motorized transportation networks which is sensitive to:
    - Time and direction of travel;
    - Number of vehicle occupants (including deadhead trips);
    - Efficient and sustainable route choices; and
    - Accessibility and equity concerns.

  Use this funding to subsidize trips for low-income individuals and replace reduced carbon and fuel tax revenues.

- Work with other levels of government to establish a programming criteria to regulate the operation of autonomous vehicles to include stipulations that they must:
    - recognize the movement of bikes and active transportation vehicles such as cargo bikes, delivery tricycles, in-line skates, and skateboards;
    - recognize emergency vehicles; and
    - make route decisions that reduce Vehicle Kilometres Travelled and emissions.

- Reinforce walkways and bikeways as space for those who are walking, cycling, using other active transportation modes or using mobility aids, rather than autonomous vehicles of any size.

- Reallocate freed parking spaces and road space to:
    - Expand the pedestrian and cycling networks;
    - Provide bicycle parking and bikeshare stations; and
    - Create public plazas and gathering spaces.

- Add the following policies to Transportation 2040:
    - To M 3.1: Support legislative and technological advances that facilitate shared autonomous vehicles and their integration with transit services.
    - To M 5.2: Support the adoption of low-carbon or electric autonomous vehicle technology.

- Determine who will regulate shared autonomous vehicle services that overlap carshare, rideshare, taxi and transit services.

- Discourage the ownership of private autonomous vehicles with financial disincentives.

Chapter 9: Other Planning and Policy Impacts & Recommendations

When autonomous vehicles arrive in Vancouver there should be robust policy in place guiding their introduction. Since AVs will impact safety, community health, environment, economy and citizen equity in the city, policy recommendations to maximize the benefits of AVs and mitigate negative impacts must be similarly far reaching.

9.1 Health & Safety

9.1.1 Safety

Perhaps the single-most compelling reason to support AV integration into our transportation network is the potential to significantly reduce the number of fatalities and serious injuries resulting from traffic collisions. In 2014, 14 people were killed and many more were injured in collisions in Vancouver (Vancouver Police Department, n.d.). At a national level, collisions cost Canada $62 billion each year (4.9% of Canada's GDP) (Godsmark et al., 2015).

If there was any single reason to adopt AVs, it would be their ability to prevent the loss of life and serious injuries that result from traffic collisions.

Many of these collisions are the result of driving under the influence, distracted driving or fatigue. If AVs are able to fully eliminate collisions caused by human error, they will eliminate 93% of all collisions, although would likely introduce new errors resulting in a more conservative estimate of an 80% reduction in collisions (Insurance Institute, 2016; Godsmark et al., 2015).

If AV technology can successful in reduce traffic collisions, this will create ripples effects within the healthcare system. Emergency departments and physicians, physical therapists and other medical professionals may see a decrease in hospital visits. Although this may lead to job loss, in an overextended health system, this would likely enable staff to work with other patients.

9.1.2 Long-term Health

AVs may also influence long-term public health in a number of ways beyond reduced traffic fatalities and injuries. The table below highlights possible City actions to support potential positive impacts and discourage negative ones.

Table 7

Potential AV-Behaviour Changes Related to Health and Potential City Actions

AV-Induced Behaviour	Cause	City Action
Reduction in Active Transportation	AV travel too convenient & cheap	Redesign streets Implement Mobility Pricing
Reduction in Stress	Commuting time spent on other activities	Encourage SAVs
Reduction in Community Connections	Longer and more isolated commutes	Maintain Density Encourage SAVs Create active public spaces

AVs may also impact Greenhouse Gas Emissions (GHG) and air quality, positively or negatively affecting the health of the Vancouver community. This will impact more than just those living, or driving on major streets as emissions affect those cycling nearby or even living several blocks away (Bigazzi, Figliozzi, Luo, & Pankow, 2015; McMahon, 2015).

The introduction of AVs represents a unique chance to require or encourage consumers or carshare companies to purchase AVs with electric (or low-emission) fuel technology which 66% of consumers already anticipate (World Economic Forum, 2015). Since most research supports an increase in VKT from the introduction of AVs, encouraging low-emissions vehicles will help us reach the Greenest City Goal of breathing the cleanest air of any major city in the world.

9.1.3 Health & Safety Recommendations:

- Support the introduction of AVs to Vancouver as a way to reduce traffic-related fatalities and serious injuries.
- Follow recommendations from Sections 7 & 8 of this paper to encourage healthy transportation behaviour.
- Encourage low-emission AV technology in AVs.

9.2 Environmental Impact

Different uses of AVs (and SAVs) will change the energy inputs and emissions outputs of these vehicles. Fagnant & Kockelman (2014) propose that emissions comparison between vehicle types should be based on (p. 9):

- "vehicle operation (in-use, VMT-based emissions and energy);
- vehicle manufacture (embodied energy);
- vehicle parking infrastructure (embodied and via parking space maintenance); and,
- and trip-start emissions differences."

Although it will be difficult to estimate these measures until AVs are available on the market, Table 8 connects new behaviours, new technologies and appropriate local policy responses.

Table 8

Potential AV-related Change Related to the Environment and City Actions

AV-Induced Behaviour	Cause	To Support or Mitigate
Increased VKT & GHG emissions	• Decreased fuel costs • Decreased resistance to longer trips & commutes	• Implement mobility pricing (distance-based charges) • Promote "green" AV programming • Support MaaS & Transit • Maintain the regional urban containment boundary.
Reduced emissions per km	• Decreased vehicle size • Change to low-emissions fuel	• Encourage reduction in size • Support low-emission vehicle purchases
Creation of deadhead VKT	• Vehicles travelling without passengers	• Implement mobility pricing (vehicle occupancy-based charges)
Reduction & reorganization of parking	• Compact mechanical parking • Able to drive to parking • SAVs reducing the total number of vehicles	• Require flexible, sharable parking • Encourage SAVs
Decreased start-up emissions and energy	• SAVs reduce "cold" starts (Fagnant & Kockelman, 2014)	• Encourage SAVs

As more extreme weather events increase the likelihood of power outages, resilient transportation system design should include resilient energy supplies, and prioritize low technology transportation choices like walking and cycling.

9.2.1 Environmental Recommendations

- Support low-carbon and low-emissions vehicles.
- Maintain the regional containment boundary to preserve ecological habitat and protect agricultural land.
- Follow Section 8.8 transportation system recommendations.

Case Study: AV Shuttles
(London, UK & Gelderland, Netherlands)

In London and in parts of the Netherlands, small shuttles holding six passengers will soon by sharing public roads. Although they may initially travel fixed routes and require a steward, eventually GATEway pods and WEpods will travel independently at up to 25 km/h. The GATEway pod technology has already been running autonomously on tracks, like several other shuttle programs like Rotterdam's 2gethere shuttle (Hodson, 2016). Users can reserve a WEpod which will travel to their railway station and pick them up (Murgia, 2016).

This type of technology can potentially solve the first and last mile problem for low-demand routes. These shuttles can move passengers to pick up locations for buses or rapid transit when they are too far from these to walk or bike. In low density areas, being able to reserve a shuttle that will arrive in in a predictable and reasonable amount of time can increase public transportation use.

Figure 19: London's GATEway pod.

Figure 19: The Netherland's WEpods.

9.3 Economic Impacts

9.3.1 Effect on Wider Economy

AV will directly and indirectly impact Vancouver's economy as well as the finances of individual households. Godsmark et al. (2015) estimates that the economic benefits from collision avoidance, fuel savings, decreased parking and productivity gains could total 65 billion in savings each year in Canada (Godsmark et al., 2015). Integrating a triple bottom line approach could yield additional non-financial benefits. For instance, a switch to electric vehicle technology may be a loss of a fuel tax, but it creates significant health and environmental benefits.

The 2205 road fatalities in Canada cost 31.54 billion dollars in 2011, meaning that each fatality cost roughly 14 million dollars on average (Godsmark et al., 2015). Additional non-fatal injuries increased the cost to 46.7 billion. Vancouver only saw 15 crash fatalities and 15,100 crash injuries in 2013, a decrease in transport fatalities and injuries could have a significant financial impact (ICBC, 2016).

The switch to low-emissions fuels and increased inputs may have additional impacts on the generation and distribution systems in British Columbia. A global reduction in fossil fuel could also impact the oil and gas industries in B.C. and across the country, although there may be employment growth in the distribution of electrical energy and connected infrastructure upgrades (CAVCOE, 2015).

There may also be additional costs associated with upgrading sustainable energy generation and distribution. At the neighbourhood-scale, local transformers may not be equipped to handle the additional load from neighbourhoods where every household charges at least one EV each night. By centralizing charging locations, a transportation focused on shared rather than privately-owned AVs could reduce costly infrastructure upgrades.

9.3.2 Effect on City Revenues and Operating Costs

AV technology could significantly impact municipal revenue streams. Table 9 summarizes some of the changes to the City of Vancouver's revenues and operating costs.

Some of these impacts might include:

- Decreased revenue from the Carbon Tax & Motor Vehicle Fuel Tax, due to increase vehicle efficiency and sustainable fuel sources;
- Reduced revenue from traffic fines, since vehicles will be programmed to obey traffic regulations;
- Decreased parking revenues from fewer parking spaces, better search capabilities and fewer violations;
- Decreased parking and traffic enforcement costs; and
- Reduced cost of wear and tear on roads from lighter vehicles, reduced collisions and better driving;
- Reduced business property taxes as work is conducted in vehicles and office space shrinks.

Table 9
Impacts of AVs on City's Revenue Streams

Revenue Source	Revenue Recipient	Revenue Amount ($)	Revenue Change	Impact on City
Motor Fuel Tax	Translink	~330 million (2012) in 2012 (Translink, n.d.)	Decrease	Reduced funding for shared cost projects and transit network
Revenue from collision & fuel businesses	City & Province	?	Decrease	Reduced City and Provincial Budgets
Refunded Carbon Tax (CARIP Funding)	City's Sustainability Group	~500,000 (est. avg)	Decrease[6]	Reduced budget for Group
Traffic Fine Refund[7]	City	13,147,456 (2016)[8]	Decrease	Reduced public safety budget
Parking	City	~50,000,000 (2015)[9]	Unknown change and impact due to possible reduction in parking revenue as well as enforcement costs	

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[6] The City of Vancouver's Sustainability Group currently receives around one million per year in CARIP funding of which $500,000 is refunded carbon tax paid by the City fleet. Of this, only $180,000 of this comes from smaller vehicles. Larger vehicles are likely to continue to run on fossil fuels rather than electrical power.
[7] The province returns 100% of the revenue to municipalities to address public safety issues through the Traffic Fine Revenue Sharing grant program.
[8] (Government of British Columbia, 2016)
[9] (City of Vancouver, 2016).

9.3.3 Effect on Industry

Although Vancouver is unlikely to become a prime testing site for AVs themselves, new AV services could spring from the gaming and sustainability-minded industries.

Gaming expertise and hardware could be used to build real-world modeling and mapping simulators. Each city has a unique layout and transportation culture which will need to be considered when programming AVs. Large-scale models run thousands of simulations in all types of conditions (including extreme weather) highlighting potential safety issues without needing to have AVs on the road. Although this seems unlikely, granular and LIDAR maps are already being created and an MIT lab has built a virtual city for research participants to interact with.

Combining Vancouver's game development expertise and its reputation as an international sustainability leader could create a unique industry niche. Vancouver modeling companies could focus on modeling incorporating active transportation, accessibility and equity.

To further buffer against possible revenue losses, the City should leverage the pre-existing technological knowledge and skills from the local gaming industry to encourage AV software and hardware that supports the Green Economy.

9.3.4 Effect on Household Finances

For individual Vancouver households, AV technology will likely impact both housing and transportation costs, the two largest expenses. Godsmark et al. (2015) estimated average cost savings of $2,8644.44[10] per household per year, in a model where only 50% of households switched to SAVs and fossil fuels are still used.[11] Although the price may come down as AVs become more common, the high costs of vehicles may encourage households to choose more cost efficient solutions, like MaaS.

In Vancouver, high land values create additional savings if vehicles and parking are shed all together. Parking stalls are worth $20,000 to $45,000 per stall (Metro Vancouver, 2014). Unbundling parking from the development and sale of properties may improve housing affordability in the city. Additionally, high turnover rates of AV fleets (on 2- to 3-year cycle due to increased VKT) will allow for rapid replacement of SAVs. Private owners may find that the high cost to keep up with technological advances may not be worth the benefits of ownership.

Mobility pricing could also discourage households from purchasing a vehicle or making long commutes. Programs like mobility pricing should continue to encourage transportation-oriented development and compact communities (Metro Vancouver, 2015).

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[10] This amount corrected for inflation from 2012 values.

[11] This simple estimate does not take into account possible savings from switch to AVs, decreased freight costs, depreciation costs, time savings, time losses or increased productivity while travelling. See Godsmark et al., 2015 for model.

9.3.5 Economic Policy Recommendations

- Support centralized electric vehicle charging infrastructure.
- Encourage local firms who are building AV-related software and hardware with sustainable and equitable transportation goals in mind.
- Implement mobility pricing to replace lost tax revenues, encourage density and discourage sprawl.

9.4 Accessibility & Equity Impacts

AV technology may change transportation patterns and costs which could change the accessibility and equity of the transportation system. A list of users who may see increased or decreased accessibility from the introduction of AVs is listed in Table 10.

Table 10
Potential System Accessibility Changes

Increased System Accessibility for:	Decreased System Accessibility for:
• Unlicensed adults • Children & young adults • Seniors • People with disabilities • Suburban users	• Low-income users • Rural & exurban Users • People without internet access • Non-English speakers

AVs will increase the accessibility of many uses who currently have limited access to the transportation system including children, seniors, unlicensed people and people with disabilities.

Although SAVs would be able to solve the last mile problem for the transit system, they would not necessarily be similar in price to mass transit. Users may be charged by distance which encourages transportation oriented development while disadvantaging those who live at outside of the core areas, regardless of income. Subsidizes and discounts through mobility pricing for low-income individuals and households may improve transportation accessibility.

Transportation accessibility will also become an issue for seniors as “aging in place” becomes more common. Research shows that seniors living independently often put off necessary trips, potentially contributing to negative effects on their physical and mental health (Bookman, 2008; Alsnih & Hensher, 2003). Providing reliable, affordable, multi-lingual and easy to use transportation will reduce health care costs and decrease isolation for seniors.

AV technology may bring a variety of other equity concerns for groups who:

- Are not fluent in English (or languages apps and instructions would be provided in);
- Are not technologically literate;
- Are not able to connect to Wi-Fi or mobile data services;
- Do not own a personal device; and
- Cannot afford mobility pricing.

9.4.1 Equity Policy Recommendations

- Consider subsidies or other ways to ensure low-income individuals and households can continue to access the public transit system, as well as other shared transportation services.
- Require new vehicles and new transportation networks be physically and financially accessible to all Vancouver residents.
- Research and promote AV transportation equity.

Case Study: AV Shuttles
(Milton Keyes, UK)

According to Brian Matthews, Head of Transportation Innovation for Milton Keynes (MK), travel demand will rise 60% in the next two decades as the suburban town densifies. Officials believe they do not have the density to support mass transit and are instead developing small AV pods. Known as LUTZ Pathfinders, these pods travel at a maximum speed of 15 km/hr and will be allowed on sidewalks and other areas typically off-limits to vehicles. Milton Keynes is developing these vehicles to encourage domestic innovation and manufacturing (O'Sullivan, 2015).

These types of vehicles represent opportunities and challenges for MK. For residents with mobility issues, seniors and children, these pods can provide door to door service within the transit system. If transit is not feasible, they may provide a cost effective alternative. On the other hand, too many pods could increase traffic congestion and crowd walkways.

Figure 20: Milton Keyes LUTZ Pathfinder.

Chapter 10: Conclusions

10.1 Further Research

The recommendations contained in this report are preliminary. Almost every aspect of this report requires further research and discussion. The City should continue to follow and consider AV-related research as it emerges, especially regarding best practices for local policies.

When considering which companies and research to support, funding should focus on initiatives which support the City's broader sustainability, accessibility, equity and resiliency goals.

10.2 Guiding Values

As AVs are introduced to the market and to Vancouver, creating policy which interacts with this technology will become an increasingly complex process. As with any policy, anticipated effects of policies may create ripple effects through out Vancouver. Flexible policy and quick decisions will need to be made. The following guiding values (also found in section 4.4) for AV-related policy must be at the base of any future policies the City makes.

1. **Mobility** – Ensure AV technology complements active transportation and mass transit, the healthiest, cheapest, most resilient, and most efficient urban transportation networks for people.
2. **Health** – Support active lifestyles by making walking and cycling the easiest and most convenient transportation options for most trips.
3. **Safety** – Improve safety by reducing transportation-related fatality and serious injury rates.
4. **Affordability** – Ensure affordable transportation options for people of all income levels. Encourage a shared ACES approach over privately owned vehicles.
5. **Accessibility** – Make it easier for people with limited mobility to access destinations and travel within the region.
6. **Environment** – Work towards a zero transportation-emissions future, and support AV policies that encourage compact, complete communities that preserve ecological habitat and protect agricultural land.
7. **Economy** – Support a thriving local economy as well as the City's role as an international port, and encourage innovation in support of green industry.
8. **Public Life** – Support vibrant public spaces that encourage social interaction.
9. **Resiliency** – Ensure the transportation system is resilient to changes in fuel prices, climate change, earthquakes and sea level rise, unstable weather patterns, electricity outages, and cybersecurity threats.
10. **Equity** – Encourage open-source platforms, as well as adaptable technology and infrastructure that encourages innovation while ensuring a level playing field for industry partners and private companies.
11. **Data Sharing and Privacy** – Collect meaningful aggregate data to improve transportation planning while protecting privacy.
12. **Immediacy** – Begin working with regional partners today to create a coordinated policy response.

10.3 Next Steps

Throughout this document diverse and detailed recommendations can be found and are compiled in Appendix A. Many of these recommendations are not immediately actionable. However, with the values above in mind, a series of actions can be implemented by the City immediately (also found in section 4.5):

1. Establish a regional AV technology working group, led by TransLink and Metro Vancouver to research emerging issues, develop regional policies, and work with the private sector and other higher levels of government.
2. Establish ongoing dialogue with other major cities in Canada and across North America to develop a coordinated approach and advocate for AV policies that support compact, sustainable urban development.
3. Plan and invest in infrastructure that moves Vancouver closer to a green future where shared autonomous vehicles support a multi-modal transportation system and discourage private vehicle ownership.
4. Continue to work with regional partners to develop a comprehensive regional mobility pricing strategy that prioritizes active transportation and mass transit, and that is sensitive to travel time, congestion levels, and vehicle occupancy rates.
5. Continue to reinforce the Transportation 2040 modal hierarchy in new developments, community plans, transportation decisions, and civic infrastructure.
6. Consistent with Transportation 2040 direction, future proof parking in new development by designing off-street parking to be a sharable resource that can be easily adapted to different uses.
7. Consider ways to retrofit parking in existing buildings to be more easily sharable by non-residents, and support conversion to other uses.
8. Consider how street space might be adapted over time as private vehicle ownership declines.
9. Support pilot projects provided they are consistent with the above-noted principles.

Chapter 11: Appendix

Recommendations
Regulation
• Support a working relationship between the Province of B.C. and Federal Government in regards to AV standards for roads, vehicles, transit safety, mobility pricing, fines, penalties and data sharing. • Encourage AV research and testing at the federal and provincial levels including research into AV equity, liability, security and privacy.
Privacy and Security
• Encourage the federal and provincial governments to include digital privacy and security standards in the Motor Vehicle Safety Act and Motor Vehicle Act (respectively). • Avoid excessive data collection and retain only aggregate data. • Meet or exceed national and provincial privacy and security regulations for any AVs in municipal- or contractor-owned fleets. • Support companies in Vancouver who are improving AV & V2X data management. • Follow AV-related privacy and security discussions.
AV Programming
• Encourage national and international AV programming standards, especially those which will help meet the Transportation 2040 zero traffic fatalities and serious injuries goal. • Support sustainable & equitable AV programming and design regulations. • Follow legal, regulatory and ethical discussion related to AVs.
Employment Transition
• Encourage the Provincial and Federal governments to research retraining programs. • Encourage Drivers Services to train drivers in AV maintenance as these vehicles are incorporated into the City's fleet. • Encourage local AV technology pilots that support the green economy. See section 9.3.5 for additional recommendations. • Promote programming and engineering education at local schools and post-secondary institutions.

Street-Scale Infrastructure
• Design streets and intersections that prioritize walking, cycling, and transit users. • Future proof any upgrades to electronic signaling infrastructure. • Support a shared AV approach that reduces the total number of vehicles on the road, through measures such as comprehensive mobility pricing. • As the total number of motor vehicles decline and on-street parking becomes obsolete, convert road space towards people-friendly pick-up/drop-off mixing zones, improved walking and cycling infrastructure, mass transit, enhanced public space, and other civic priorities. • Explore how AV technology and connected V2X infrastructure could ensure location- and time-base traffic rules and regulations with 100% compliance, including speed limits and access restrictions. • Consider implementing street hierarchies or zones within the city and region where different types of vehicles are and aren't allowed, e.g. AVs versus non-AVs, non-motorized zones with limited exceptions, etc.
Parking
• Require parking in new developments to be shareable by non-residents and non-tenants. In the short-term, this supports the unbundling of parking, positively impacting housing affordability. In the long-term, this enables utilization of the space by shared vehicles, supporting a shared autonomous vehicle rather than private autonomous vehicle model. • Develop a retrofit program to make it easier to share parking in existing buildings. • Design parking to be adaptable to other uses, considering that future parking requirements will be greatly reduced. • Consider where future shared parking and charging locations are located, how they are managed, and how these decisions can impact VKT and travel behaviour. • Continue reducing parking minimums for developments, renovations and infill. • Create mobility pricing and parking fee structures which will encourage shared autonomous vehicle use and discourage lengthy deadhead trips to find "free" parking. • Encourage a shared, rather than privately-owned, AV model to reduce parking space and free land for other uses. • Identify on- and off-street parking that could be converted to other uses that fit long-term planning goals.

City-Scale Infrastructure

- Develop coordinated regional and provincial responses to AV technology which support compact sustainable urban development and discourage auto-oriented sprawl.
- Develop a comprehensive regional mobility pricing strategy that prioritizes active transportation and mass transit, and that is sensitive to travel time, congestion levels, and vehicle occupancy rates.
- Create AV policies that support Metro Vancouver regional growth strategy goals by encouraging compact, complete communities; protecting rural, agricultural and natural lands; and supporting sustainable transportation and transit-oriented development.
- Anticipate significant changes to traffic patterns and pressure on the urban containment boundary.
- Set AV traffic speeds which:
  - Encourage residents to walk, cycle and use transit for shorter trips,
  - Respond to nearby road users, including those cycling,
  - Discourage sprawl by maintaining current highway speeds.
- Rather than invest in costly projects to expand road capacity, like the Massey Tunnel Replacement Project, implement a future proof audit system for all major infrastructure projects.

Transportation System

- Support AV, shared autonomous vehicle & Mobility as a Service technology that will:
  - Improve rapid transit and local transit;
  - Improve transit reliability and equity;
  - Address transit network gaps;
  - Reduce dependence on personal vehicle ownership;
  - Reduce VKT, emissions and congestion; and
  - Return commute and errand time to individuals.
- Implement mobility pricing across all motorized transportation networks which is sensitive to:
  - Time and direction of travel;
  - Number of vehicle occupants (including deadhead trips);
  - Efficient and sustainable route choices; and
  - Accessibility and equity concerns.

  Use this funding to subsidize trips for low-income individuals and replace reduced carbon and fuel tax revenues.
- Work with other levels of government to establish a programming criteria to regulate the operation of autonomous vehicles to include stipulations that they must:
  - recognize the movement of bikes and active transportation vehicles such as cargo bikes, delivery tricycles, in-line skates, and skateboards;
  - recognize emergency vehicles; and
  - make route decisions that reduce Vehicle Kilometres Travelled and emissions.
- Reinforce walkways and bikeways as space for those who are walking, cycling, using other active transportation modes or using mobility aids, rather than autonomous vehicles of any size.

- Reallocate freed parking spaces and road space to:
  - Expand the pedestrian and cycling networks;
  - Provide bicycle parking and bikeshare stations; and
  - Create public plazas and gathering spaces.
- Add the following policies to Transportation 2040:
  - To M 3.1: Support legislative and technological advances that facilitate shared autonomous vehicles and their integration with transit services.
  - To M 5.2: Support the adoption of low-carbon or electric autonomous vehicle technology.
- Determine who will regulate shared autonomous vehicle services that overlap carshare, rideshare, taxi and transit services.
- Discourage the ownership of private AVs with financial disincentives.

Health & Safety

- Support the introduction of AVs to Vancouver as a way to reduce traffic-related fatalities and serious injuries.
- Follow recommendations from Sections 7 & 8 of this paper to encourage healthy transportation behaviour.
- Encourage low-emission AV technology in AVs.

Environmental

- Support low-carbon and low-emissions vehicles.
- Maintain the regional containment boundary to preserve ecological habitat and protect agricultural land.
- Follow Section 8.8 transportation system recommendations.

Economic

- Support centralized electric vehicle charging infrastructure.
- Encourage local firms who are building AV-related software and hardware with sustainable and equitable transportation goals in mind.
- Implement mobility pricing to replace lost tax revenues, encourage density and discourage sprawl.

Accessibility & Equity

- Consider subsidies or other ways to ensure low-income individuals and households can continue to access the public transit system, as well as other shared transportation services.
- Require new vehicles and new transportation networks be physically and financially accessible to all Vancouver residents.
- Research and promote AV transportation equity.

Chapter 12: Glossary

AV: An autonomous vehicle, a vehicle which can perform all the operations required to pilot itself with out external intervention.

ACE: Autonomous, connected and electric. An ACE vehicle has self-driving, internet connectivity and electric vehicle technology.

ACES: Autonomous, connected, electric and shared. Like an ACE vehicle, but is also a shared vehicle, like a carshare or rideshare vehicle.

ADAS: Automatic Driver Assistance Systems which assist the driver such as an automatic braking or intelligent cruise control system.

Deadhead trip: An AV vehicle trip without a passenger.

First & Last Mile Problem: Within a transportation system, the difficulty in taking users from the closest transportation stop or hub to their final destination or from origin to a transportation stop.

Future Proof: Building infrastructure, software, etc that can be used in the future by anticipating future changes to technology.

MaaS: Mobility-as-a-Service. A transportation system where users pay for a variety of services (sush as bikeshare, carshare and mass transit) through a single gateway, usually an app.

Platooning: When a group of vehicle drives as a single unit using AV technology. Vehicles could potentially drive closer together.

SAV: Shared autonomous vehicle. A vehicle which a user can request pick-up and drop-off a passenger, can be a multi-occupancy vehicle.

TaaS: Transportation as a Service. See MaaS.

VKT: Vehicle Kilometers Travelled, a unit which measures the total kilometers travelled by a vehicle or vehicles.

Chapter 13: Additional Resources

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