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PLANNING FOR AUTONOMOUS VEHICLES

IMAGINING ALTERNATIVE FUTURES

TECHNICAL REPORT

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Planning for Autonomous Vehicles: Imagining Alternative Futures is a studio-based academic undertaking in partial fulfillment of the requirements for the degree of Master of Planning in Urban Development at Ryerson University. This report has been prepared by a team of students in the School of Urban and Regional Planning, in consultation with academic and professional advisors. With special thanks to our supervisor, Dr. Matthias Sweet for his ongoing guidance and support.

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(RAND CORPORATION, 2016)

"In anticipation [of autonomous vehicles], Transportation Services has established a Working Group to foster the development of policy, regulations, standards, and guidelines that will help us to **shape the City we want, and not simply react** to this technological change as it occurs."

- Congestion Management Plan, 2016-2020

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1.0 PROJECT BACKGROUND

1.0 PROJECT BACKGROUND

Our studio group has been retained by the Transportation Services division of the City of Toronto to explore how the adoption of autonomous vehicles (AVs) in the Greater Toronto and Hamilton Area could unfold. This will be accomplished by presenting potential scenarios and the implications resulting from the adoption of AVs. The goal of the studio project is to explore and identify the key levers and conditions necessary for the adoption of the autonomous vehicles, and to present possible future scenarios of urban mobility influenced by the use of AVs. An iterative research process, consultations with the City of Toronto's Autonomous Vehicles Working Group, mentors - Steve Erwin, Dewan Karim, Steve Buckley,and David Ticoll - and feedback from our clients, Ryan Lanyon and Fahad Khan, and supervisor, Dr. Matthias Sweet, informed the development of comprehensive, realistic scenarios.

This report provides key background information supporting and grounding our scenarios. Given that the autonomous vehicle is a disruptive technology, scenario building is an essential tool for robust decision making in the face of uncertainty. Our scenarios act as test beds for plans and policies. They provide an opportunity for government and policy makers to envision different futures where they may have to play a key role in ensuring that our society captures the benefits of autonomous vehicles while mitigating any negative consequences.

2.0 METHODOLOGY

2.1 SCENARIO BUILDING

While researchers remain divided on the number of steps required in scenario building, there is a general consensus on the essentials required. The process begins by identifying the key conditions that will have a decisive influence and likely determine the course of future events (Van der Heijden, 2005).

Through a literature review and conversations with our client and mentors, we identified four key conditions that will influence the deployment of AVs in the Greater Toronto and Hamilton Area: technology, safety, economics, and attitudes.

Next, we constructed initial scenario frameworks by creating combinations of positive and negative conditions. For instance, technology may develop rapidly with high safety benefits, and positive public attitudes, but autonomous vehicles remain unaffordable. The most interesting scenario frameworks were kept, and others that were less relevant or lacked internal plausibility were discarded (Schoemaker, 1995).

With frameworks in place, we began the search for effects, by drawing on our large collection of data and conducting further research when blind-spots were identified. While the implications of AV adoption are perhaps innumerable, we identified twelve areas where they are anticipated to have sizable impacts. These twelve implications are explored further in this report. At this stage, we also made use of modeling techniques to quantify certain interactions and deepen our understanding of the consequences of our scenario conditions in this region. The rationale and assumptions behind the model are also explained in further detail in later sections.

The final step in scenario building is developing the research into a story. For each implication, potential events were created to illustrate how these identified consequences could play out in the GTHA. Woven together, these stories are intended to be engaging and to provoke broad thinking and discussion about what a future with AVs might look like. We hope you enjoy them.

2.2 MODELING

To determine the potential impacts AVs will have on TTC ridership and operations, we must first estimate the degree to which AVs will be adopted within the GTHA. Other determinant factors include the prevalent ownership models, the estimated number of users for each technology, and the overall impact each AV type has on the city it operates in. To achieve this, a two-step modelling process was utilized. In Step 1, overall adoption rates are estimated based on mutual interactions between our necessary conditions. In Step 2, the benefit and consequences of these adoption rates are measured, and fed forward into the next iteration of the model. Proceeding as such, the model calculates the impact in five year increments until the year 2036. AV adoption rates were based on interactions between technology, safety, economics, and attitudes, (*Figure 1*) with assumptions from literature.

Step 1: Estimating AV Adoption

Estimates of AV adoption rates were made utilizing interactions between the initial conditions of each scenario. To begin, each condition (Technology, Safety, Economics, and Attitudes) were assigned a weight describing the degree to which it was believed to influence both the overall adoption rate of AVs, as well as the other conditions of the model (see *Appendix*). Contributions to adoption rates were assumed to occur *only* when associated conditions were positive, and as such, negative starting conditions produced less overall adoption.

Natural changes in the necessary conditions over time were estimated using interaction weights between all four conditions. These weights are iteratively calculated at each five year step of the model. Further, the rates of adoption themselves fed back into the growth of conditions to simulate the impacts of market demand on the overall development of the technology, and utilized to calculate condition growth rates at five year intervals. For example, negative economic conditions will slow the overall growth of positive attitudes, while negative attitudes will slow the growth of economic conditions through a slow market. Thus, in a scenario where both are negative, positive growth will take longer and adoption will be postponed.

The model's maximum (capped) adoption rate was 20%. This value was identified by Tod Litman, who estimated adoption rates based on vehicle turnover rates and the automotive industries past behaviors regarding the introduction of other technologies, such as automatic transmission (Litman, 2016).

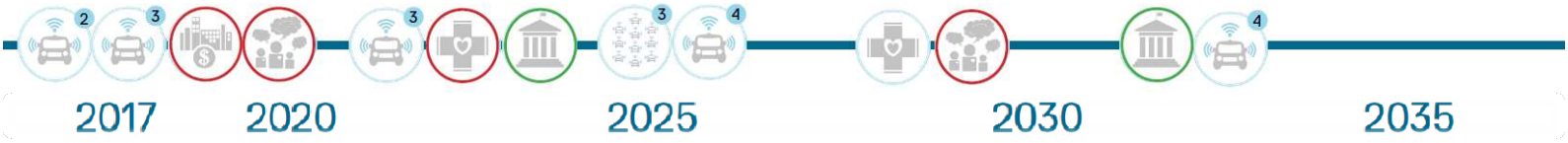
Mode share was determined using the assumptions that significant SAV growth would not be viable (from a business perspective) until both economic and attitude conditions were positive. Some slight growth is permitted in negative conditions, but the greatest growth occurs if attitudes and/or economics are positive. This method was utilized due to great uncertainty in literature regarding the prospects of AV ownership models.

Step 2: Calculating the Impacts

Adoption rates, and the proportional split of private and share Avs (PAVs and SAVs) are then utilized to calculate the impact of AVs on transportation networks of the GTHA. The method and assumptions utilized to calculate these variables can be found in the assumptions table of the *Appendix*. Fare count estimates were determined by multiplying the total number of commuters in the GTA by the adoption rates of both SAVs and PAVs.

3.0 SCENARIOS

PART I: PHANTOM AVs



You are in 2017, and you could go out today and buy a car with adaptive cruise control and lane assist. Your car will sense the lines on either side of you and keep you between them. It will also slow down if it senses something in front of you, even bring you to a complete stop and restart you again in stop and go traffic. Congratulations! You are driving a level 2 automated vehicle. But are you safer? Are those around you safer?

Within the next few years, you see level 3 autonomous vehicles being released by Tesla, Google, and other companies with much fanfare but without any mass-production due to their high price premium. These vehicles can drive themselves in certain situations, like on a highway, but require a driver to be on the alert, ready to intervene when necessary.

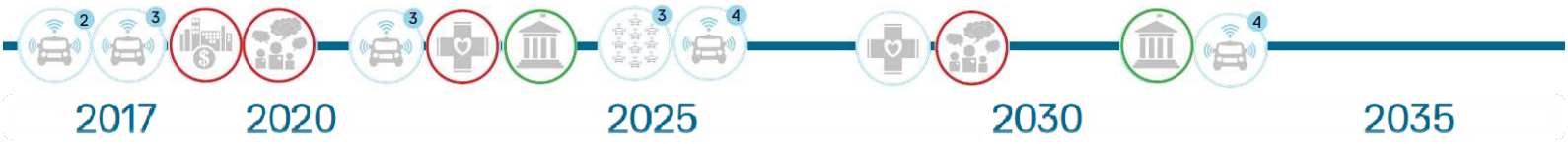
For the general public, lower level assistive technology becomes available in more and more new vehicle models. Car manufacturers advertise the safety benefits of their vehicle's "Smart Sense," and how a growing number of sensors "See what you miss!" thereby helping to prevent collisions.

Your car can now connect you to the internet while you are driving to work using LTE cellular technology, as well as communicate with other cars using DSRC technology. Similar to a chain reaction, information about speed, braking, and steering wheel position is transferred from one car to the other, building a detailed picture of what is happening on the roadway to allow for smart routing and smoother traffic flows.

Still, you are not that impressed. These technology add-ons come at a pricey premium, and while early adopters, like your tech-savvy neighbour Seungwon, are quick to get on board, the rest of the neighbourhood is slow to see the value. Many of the sensors do not work in snow, heavy rain, or on roadways with faint markings, and while having wifi in your car is nice, it requires a monthly subscription.

Overall, due to slow adoption, the benefits of cars being connected to one another do not materialize. Better traffic data is available through your smartphone, and most people find it a bit creepy that your car is broadcasting data about your driving habits. Questions arise about ownership of the data and who can access it. Your neighbours, Patricia and Alyssa, are convinced that an insurance company could use it against you to avoid paying out a claim or to increase your rates.

PART I: PHANTOM AVs



It is now 2020, and luxury level 3 AVs are becoming more available. However, it seems that, although the technology was tested exhaustively, including in winter conditions on Ontario's roadways, what did not get tested enough was the human-machine interface and the very real possibility that drivers would mis-use the technology. You turn on the television and hear some troubling stories. A film star in California put his Tesla in level 3 automated mode and drove home drunk. When the car asked him to take over on some hairpin turns, he skidded off the road and ended up halfway down a cliff to the ocean.

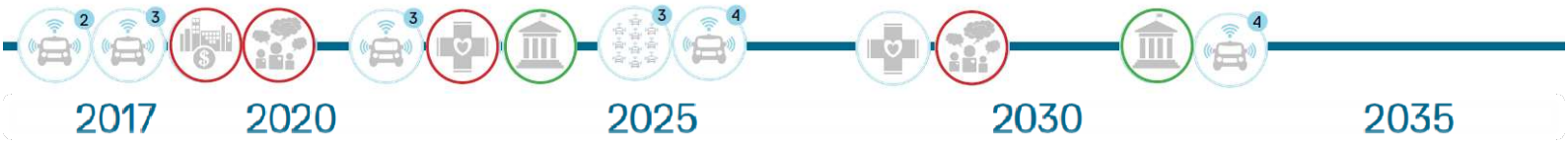
These incidents start to occur closer to home. You read in Metro Toronto about people getting photographed checking email on the Don Valley, reading a book in stop-and-go traffic on Eglinton or, in a video that goes viral, knitting on Yonge St. The police intensify their campaign against distracted driving, but it does little. Imagine yourself daydreaming out the window at some beautiful bit of countryside when a warning bell suddenly goes off because your car, which was driving itself, has strayed onto the gravel. It is impossible to re-engage instantly; you need a second or two to readjust and shift yourself from relaxing to actively driving. Collisions occur. Many are fender-benders, caused by these vehicles' propensity to stop unexpectedly when they find themselves in a situation where they need guidance but none is immediately forthcoming.

In response to these issues, car manufacturers add "Drive Alert" safety features. These start out as icons on the dash that light up at random while the vehicle is in automation mode, and which you must address within a certain timespan for the car to continue, otherwise it will slow to a safe stop. The exercises to re-engage become increasingly complex, as manufacturers try to stay ahead of the Youtube videos showing how to outsmart them.

Then the inevitable finally happens in Toronto: a driver playing World of Warcraft in stop and go traffic on Lawrence Ave hits a pedestrian. Alongside your neighbours and walking and cycling activists, you march to City Hall, demanding that limits be placed on these "Killing Machines," and harsher punishments for distracted drivers. The World of Warcraft driver is charged with criminal negligence causing death.

At this point, it is 2025, and level 3 vehicles are available to the general public, though at an added cost of $10,000. The provincial government mandates that level 3 autonomous vehicles may only be used in automated mode on controlled access highways and on regional roads "where indicated." Municipalities begin to pass by-laws controlling which streets will accommodate AVs and which will not. Generally, automated mode is permitted on regional roads outside of town, but must be turned off when the speed limit drops in a built up area.

PART I: PHANTOM AVs



In order to enforce this, the government requires manufacturers to have an exterior indicator light, showing when automation mode has been switched on. Toronto also begins promoting "Stay Alert" zones around schools and in pedestrian-frequented areas.

You start reading stories of level 4 vehicle prototypes being released in some very well-mapped US cities. These vehicles can purportedly handle almost all types of driving. You hear that manufacturers are facing technical barriers to removing the driver completely, as the urban street environment is too uncertain and too changeable, and machine learning is not advanced enough to handle it. You hear about a study on the safety benefits of adaptive, connected and collision prevention technology. But you and your neighbours' mistrust is solidified. It seems everyday on the news, there's another crash by another driver, who found a new ridiculous activity to do in these vehicles.

Against this backdrop, shared, on-demand mobility continues to grow. A new Uber spin-off called Friend is released. It is specifically marketed as non-automated, and its slogan is, "Our cars are driven by people, and by people alone."

The growth in shared mobility has considerable environmental and congestion benefits as young people increasingly decide they don't need to buy a car, and seniors find they can give up their cars and still maintain a high degree of independent mobility. Less car ownership means transit ridership increases with shared mobility filling in last-mile network gaps. Mobility is considerably different than twenty years ago, even without full automation.

PART II: INDUSTRY STRIKES BACK

The year is 2025, and rapid innovation and heavy investment from the automotive and technology sectors means that entirely driverless vehicles, Level 5s, are achieved but at an extraordinary price premium, putting private ownership in the realm of luxury car purchasers only. Audi, Mercedes, and BMW all have models around the $90,000 mark. Chances are, you are not buying one, although Lady Gaga arrived to the premiere of her new movie in an AV, and Drake drove one onto the stage to go with his new song, “AV Bling”.

You see an episode of ‘Top Gear’ where they tour the new Lincoln AV. It has plush seating, a bar fridge, and a floor-to-ceiling, voice-activated screen for setting your destination. Discretely hidden away is a control panel and an emergency stop button.

While the first celebrity appearances in AVs are police escorted, on closed roads, many US states quickly pass legislation that make safety-certified AVs legal with no licensed driver required, and Ontario follows suit. With the new regulations, the RV sector sees an opportunity for self-driving luxury RVs. Marketing the AV RVs as “The Home of the Future”, you can program your RV to take you anywhere at anytime while you sleep, cook dinner, take pictures of the countryside, or play boardgames with the family.

You see commercials for these vehicles, but you drive a functioning but not fancy hatchback you bought 10 years ago. You often drive out to Kitchener to visit your parents, and when you return home late at night, you are fascinated by the platoon of automated trucks with no drivers that take up one lane of traffic on the 401. Marked off by traffic pylons, the designated lane is part of a long-haul, automated trucking pilot project being put on by the Ontario government. The trucks are supervised remotely, with several staff people on the ground, accompanying the convoy in case there are any issues. A media campaign is launched in support of the pilot and it seems like every time you turn on the TV or scroll through the news on your phone, there is an ad featuring the province’s new slogan: “We’re helping Ontario move itself into the future.” You are not surprised to hear on the news the next morning that the pilot will be expanded to off-peak daytime hours, although rail freight companies begin to grumble about this preferential treatment

PART II: INDUSTRY STRIKES BACK

2017 2020 2025 2030 2035

Of course on the way to work, you wonder, if automated trucking is possible, why are buses still being driven by a driver? You read in Metro Toronto not only about how much fares could be reduced, but also about how safe automation is. The transit workers have been protesting on a regular basis in front of Queen's Park and City Hall, but their jobs are a lot more secure than those of the truck and taxi drivers who are not strongly unionized. The government has put in place generous skills re-training and early retirement programs, so you are not too sympathetic. You would really rather just pay less for transit.

Five years later, your car finally passes on, and you decide not to replace it. You have been finding it really easy to get around town in the new shared AVs, especially ever since all mobility options were put on a single platform. You love that you do not need six different accounts anymore - one app does it all. It is cheaper as well because there is no need to pay for parking, maintenance, insurance, licensing fees, and all the other costs, and you do not have the stress of having to pay attention at all times while you drive.

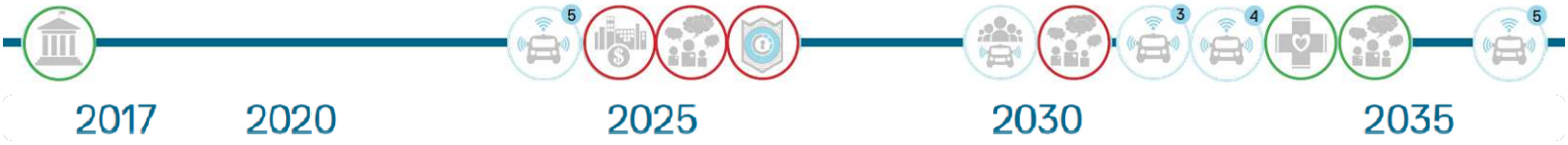
You now take a small, two-person, on-demand electric AV to the Appleby GO train station, and the fare cost is subsidized by Metrolinx. Your neighbour, Seungwon also takes an SAV to the GO, and when they announce plans to turn one of the surface parking lots at the station into a mixed use development, you think that it sounds like a great idea. There is no need for all that parking anymore.

(LAVRINC, 2013)

Downtown is full of SAVs, and some of the on-street parking has been replaced with curbside pick-up/drop off zones instead. You hear that all this new on-demand mobility has decimated ridership on Oakville's buses, but from what you can see, the subway and GO train are as full as ever.

You're happy too because SAVs have even made it out to Kitchener now, and your parents are getting to the point where they probably shouldn't be driving themselves. They still live very active lives, though, and were keeping a vehicle to be able to get to their afternoon aquafit classes at the community centre. You convince them to try taking an SAV instead, and they are quick adopters.

PART III: RETURN OF PARTIAL AUTOMATION



You are again in 2017, and you live in the GTHA where the provincial government has been proactive in regulating autonomous vehicle technologies. Car manufacturers were announcing with much fanfare the release dates of their semi-autonomous automobiles, but Ontario, along with many other jurisdictions, followed NACTO's recommendation and drew up legislation restricting the use of any AV not capable of full automation on city streets. For example, level 3 can only be used on controlled access freeways and provincial highways.

It is now 2025, you are 8 years older, and level 5 automation is available to purchase. However, they are expensive at a premium of $50,000 because of the enhanced technology required to navigate in challenging conditions, such as snow. These are a luxury good and are marketed as such. The vehicle's design encompasses spacious seating and an ipad like device to enter your destination coordinates. In an effort to popularize the technology, you see car manufacturers crisscrossing the country with their AVs, doing test rides and advertising heavily.

In general, though, you and your neighbours remain cautious as autonomous vehicles become a popular target on talk shows. Rick Mercer goes for a ride in one and calls it, "One of the scariest things I've ever done!", and Ellen Degeneres, in a couch conversation with Paula Abdul, voices that she'd "still really want my hands on the steering wheel, even if it was 100% automated."

More and more, you hear of panels that are organized to discuss the ethical dilemmas of the technology and "the code to crash." You wonder "in an emergency situation, does the AV privilege the life of the driver or that of a bystander?"

You hear Brad Paisley's new hit song on the radio, "*My Truck Don't Drive Itself*," which holds the top position on the Country Billboard charts for 21 weeks. You can't help yourself but sing along:

These new cars...I'm not sure.
There's something about driving, ya'know?
Getting a little mud on the tires?
That's at the heart of America.
It's just not same if you don't do it yourself.

Deep down, you realize that this song expresses the sentiments of everyday, down-to-earth people.

PART III: RETURN OF PARTIAL AUTOMATION

Then one or two car-jackings take place. You hear it on the news: a woman was riding in her AV to work when things suddenly started happening. None of the controls were working. The map on the screen was replaced by a creepy raven image, and the car exited the highway on its own. She tried calling for help, but her cell phone, which had been connected to the vehicle's wifi, was also blocked. A message appeared on the screen: provide your bank account information to be released. She does, and is let go, but the experience is traumatizing.

Car companies scramble to release patches and explain how their cars' enhanced security features make them completely unhackable. You read in the newspaper that Elon Musk lambasts the public for not understanding the collective safety benefits to be captured, and letting one or two security glitches stand in the way of progress. He remarks that "these vehicles are so safe that I'd put my 5 year old grandchild in it and send him across the country."

You notice car dealerships begin to be targeted with the slogan, "Take back control!" Public opinion of AVs is so low that you are surprised when you open your uber app and discover that the company is offering a new system called "Uber Sense", a spin-off with automated vehicles. You stick with the version that comes with a driver, despite it being slightly more expensive.

Due to the unpopularity of full automation, Mark Fields, the CEO of Ford, publically announces the re-introduction of the driver's seat and steering wheel, saying that, "if they want to have full control over the vehicle, they may have it."

This automation-by-choice version is more popular than full automation alone. While still expensive - they have a price premium of only a few thousand dollars - you appreciate being able to choose when you would like some automation and when you would like to drive yourself.

These vehicles also offer consumers another choice: to be or not to be connected. Automation is achieved entirely through cameras and LiDAR, without broadcasting or receiving any information from other vehicles. Less connectivity reduces the risk of attack, and the vehicles' encryption and firewalls make hacking even more difficult.

With this increased level of personal choice and control, you notice that attitudes begin to shift. As people gain more experience with partial automation, they become more open to full automation, and shared AVs make a comeback in the marketplace. It looks like an AV-friendlier world may be in your future.

PART IV: ATTACK OF THE AVs

2017 2020 2025 2030 2035

It's 2025, and the past nine years have seen rapid innovation in AV technology. Fully self driving cars are not only available, safe, and able to navigate in complex conditions, they are affordable, with a price premium of only a few thousand dollars. Governments have had to move equally quickly to pass legislation regulating these vehicles. In Ontario, a safety-certified AV can be ridden with no licensed driver, clear federal standards govern the collection and use of data, and manufacturers provide their vehicles with regular security updates to guard against cyberattacks.

You've been driving the same old beater of a car. It finally dies, and you find yourself in a dealership, standing in front of a shiny new AV. You think about your commute into work everyday: 45 minutes of sitting in a vehicle, hands on the wheel, in stop-and-go traffic. You consider the possibility of 45 minutes of extra sleep, or catching up on the newest episode of the Walking Dead inside your comfortable vehicle. You're essentially buying time - time just for yourself, where you can kick back and relax. Suddenly, the $3,000 seems really worth it. You buy an AV. So does your neighbour Seungwon and a lot of other people.

You are really happy with your new purchase. You love that quiet time at the end of your day when you can be alone, watch a TV show and eat some take-out food. You used to ride the GO train to work, but now you just take the car. The best part is that you don't even need to pay for parking - you can send it home, or download the *Park for Free* app, and the car will park in the closest spot available where it will wait further instructions. Maybe you start thinking about living further from work given the convenience and affordability of the vehicle.

Downtown, you see many shared AVs. They are mostly two-person pods and much smaller than what you bought. They have completely replaced human-driven taxis, and their fares are really reasonable. On-street parking close to transit stations has been replaced with SAV pick-up and drop-off zones, as they are especially popular with people who do not own cars and prefer them over taking a bus. However, you and your friends are not using the SAVs because you already bought your own private AV.

In the suburbs, there are even fewer SAVs, but they are already having an impact on transit ridership. Municipalities want to be sure that everyone has transit access, but they are beginning to wonder how they can continue offering transit service when SAVs are taking over the market and are just as accessible.

PART IV: ATTACK OF THE AVs

2017 2020 2025 2030 2035

(URBAN TORONTO, 2016)

You feel like you are part of a movement. As AV usage continues to grow, your neighbour Seungwon talks excitedly about Vision Zero being achievable. It is true... the number of fatal crashes and minor collisions have declined significantly over the past couple of years.

On the weekend, you go down to Kitchener to visit your parents and take them for a ride in your new AV. Your mother had to give up her license a year ago, and your father really shouldn't be driving anymore either. You show them how easy it is to use an SAV and how all the sensors make it safer than a human driver. You're not surprised when you get a call from them the next day saying they've decided to buy one. You're thrilled that they'll be able to get around independently, without the worry of driving. Yet, you wonder what they'll do if in the future they need a wheelchair or help getting in and out of the vehicle.

You see empty AVs driving around more and more often. SAVs circle while they wait for passengers, and people send their personal AVs back home or to find free parking while they work or run errands. You also discover the miracle of AV-enabled online purchases. More and more stores begin offering this service, where you place an order and provide a license plate number of an AV. The AV is then sent to pick-up the purchase once it is ready. No need to drive to the nearest Canada Post.

With all these extra trips added on top of a growing population, the roads are feeling crowded. Yet, because traffic is still mixed, the potential capacity-saving benefits of platooning AVs are not really achieved as AVs still have to keep their distance from human drivers. The government begins to come under pressure to create AV-only lanes to allow for more effective platooning and efficient travel.

PART IV: ATTACK OF THE AVs

2017 2020 2025 2030 2035

However, the government comes out against these AV-only lanes because they encourage more private, and empty AV use. Instead, the Premier announces that, "Autonomous vehicles, as a disruptive technology present an unique opportunity to re-think road pricing. We cannot build ourselves out of congestion, we must price ourselves out of it." Following this announcement, the government proactively tries two approaches to reduce congestion:

1. Cordon Pricing: There is a fee to enter the downtown core. Cars are charged electronically when entering the limits of the core zone through a license detection system. This substantially increases the cost of commuting by AV to and from the downtown core, and so you stop sending your car home during the day. However, the pricing scheme does not really have any effect on empty vehicles circling within the zone, or on empty VKT in municipalities outside of Toronto.

2. Empty Vehicle Charge: Vehicles are charged per kilometer of use when empty. This more directly combats empty, passenger-less car rides, for example when private cars are programmed to drive away and find free parking while you pick up a coffee. While the charge is applied to both private shared autonomous vehicles to prevent excessive circling, a significant impact on congestion is not seen because AVs are not often without a passenger.

As you can imagine, these policies make AV travel more expensive. Although you still enjoy traveling in your AV, you take the GO train once in a while now to save money. Your neighbours, Patricia and Alyssa, who were considering buying an AV, now decide not to. They take SAVs and transit instead, and with this new pricing system in place, the number of SAVs on the road surges. The future looks like collective benefits will take priority over private convenience.

4.0 BACKGROUND

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

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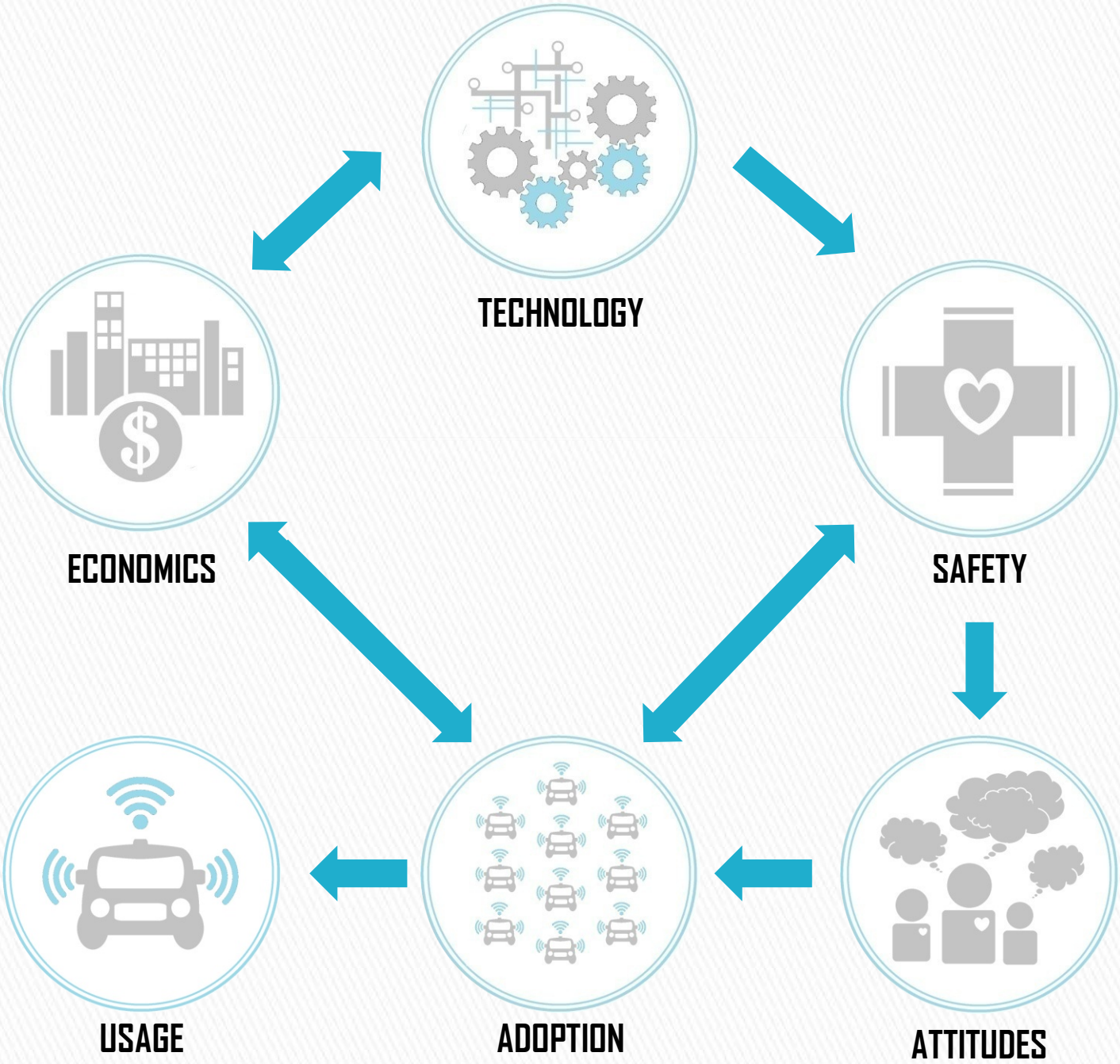
4.1 LEVELS OF AUTOMATION

A definition is needed in order to critically explore autonomous vehicles in our scenarios. Broadly, autonomous vehicles are self-driving cars which use sensors, telecommunications, and GPS to improve the safety and efficiency of a vehicle. The degree of autonomy varies - the Society of Automotive Engineers categories vehicles into the above categories.

4.2 KEY CONDITIONS

Figure 1: Condition Interactions.

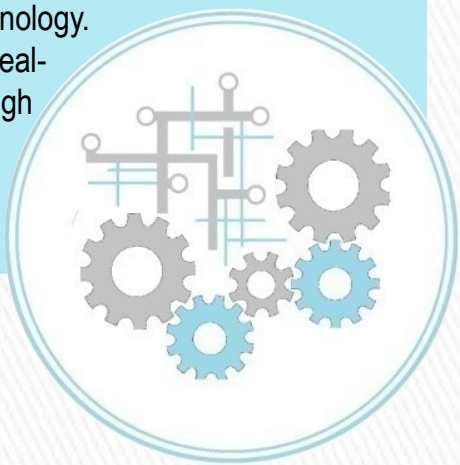


4.2.1 TECHNOLOGY

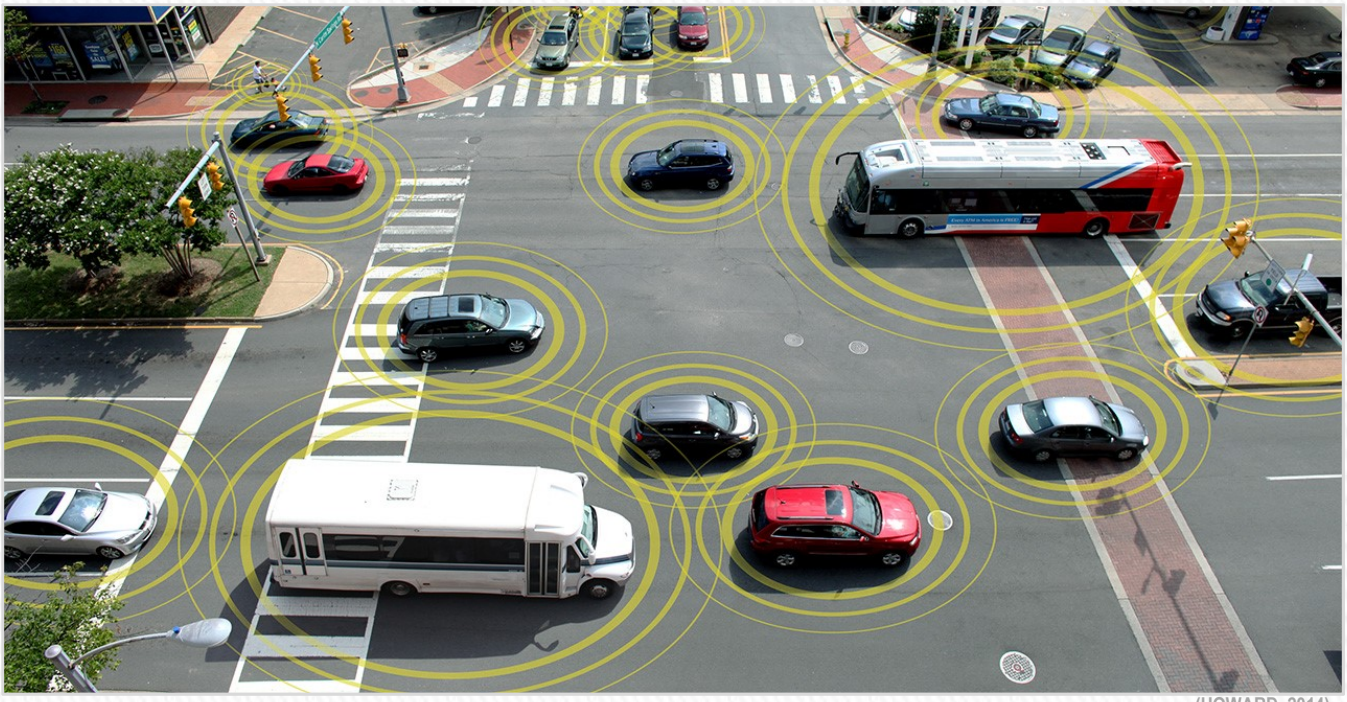
Technology is explored by its rate of progress through levels of automation and communications. In a study designed to forecast the total sales of autonomous vehicles to 2035, IHS (2014) predicts that by 2020, vehicles will have level 3 capabilities, followed by level 4 capability later in that decade. Litman (2016) anticipates that by 2030, AVs will represent slightly over 20% of all vehicle sales; however these vehicles will likely be restricted to certain roadways.

More ambitious forecasts often fail to fully specify the vehicle's automation level. Thus, while Ford, General Motors and Volvo have all announced the release of self-driving cars by 2021 or earlier, these vehicles will be limited to small geographic areas that have been mapped in intricate detail. Some see the promise of a vehicle capable of full autonomy at all times as unfulfillable. Prentice (2016) points to the constantly changing and uncontrollable environment of the roadway as being impossible to model and not conducive to smart machines. He also states that major, unresolved problems in machine learning, including reward hacking, handling distributional shifts and reinforcement learning without catastrophe, make a fully autonomous vehicle unachievable, at least within a reasonable timeframe.

For communications, AVs may operate on two types of technologies: Vehicle to Vehicle (V2V) (*Figure 2*) and Vehicle to Infrastructure (V2I) (*Figure 3*). For V2V communication, Dedicated Short Range Communications (DSRC) have been identified in North America as the most likely technology to be utilized; this bandwidth has been reserved for Intelligent Transportation Systems (ITS) since 2006 and would be suited to communications between vehicles in close proximity to one another. Data shared would include speed, steering wheel position and brake activity, and the subsequent chain of information would allow for much smoother flowing traffic. However, other interests are lobbying for access to this bandwidth, and concerns have been raised over whether DSRC would be able to support the huge volume of information traffic from a fleet of connected vehicles (U.S. Department of Commerce, 2013). V2I communication, and possibly for V2V as well, is generally anticipated to use Long-Term Evolution (LTE) technology. Google and TomTom already use cellular technology to produce real-time traffic congestion maps. While the technology's capacity is not high enough to support mission-critical safety purposes currently, the coming of 5G LTE is expected to coincide with the development and deployment of Avs (Luoto et al., 2016).



4.2.1 TECHNOLOGY – V2V AND V2I



(HOWARD, 2014)

Figure 2: Vehicle-to-vehicle communications (V2V).

(C3 GROUP, 2014)

Figure 3: Vehicle-to-infrastructure communications (V2I).

4.2.2 SAFETY

The World Health Organization (2013) states that traffic accidents were the leading cause of death among young adults 15–29 years old, and the second-highest cause of death for children 5–14 years old. Further, 90% of all accidents are the result of human error. Safety is thus often cited as one of the prime motivators behind AV development. It is hoped that in removing the human element from driving, collisions will be reduced, or completely avoided altogether (Anderson, 2016). It must be noted though, that an important factor connected to safety is adoption rate. The higher the number of AVs on the road, the more safety benefits actualized. Fagnant (2014) projects that at 10% of market penetration, fully automated vehicles will provide a 50% reduction in crashes and injuries. A 90% market penetration will likely be needed to achieve a result of 90% reduction in collisions (Ticoll, 2015).

Some research suggests that even at low levels of automation, safety benefits exist; the Insurance Institute for Highway Safety (IIHS) estimated that if all vehicles had forward collision and lane departure warning systems, sideview (blind spot) assist, and adaptive headlights, all technologies which already exist, then nearly a third of crashes and fatalities could be prevented.

However, recent research that tested vehicles with adaptive cruise control and lane-keeping engaged (level 2 automation) found that drivers engaged in less safe behaviour and when required to intervene, exhibited slower response times (Shen, 2016). The National Association of City Transportation Officials (NACTO) recommends that vehicles with level 3 and 4 automation not be permitted on city streets because of the potential for driver distractibility and over-reliance on partial automation technologies (NACTO, 2016).

(KILCARR, 2016)

4.2.3 ECONOMICS

Affordability is a critical influencer in all the scenarios considered. It can make the difference between owning, sharing or simply not considering the adoption of this technology for traveling. Affordability was approached from the price premium paid for this technology and the price per mile traveled.

IIHS (2014) asserts that the extra premium car-purchasers would have to pay for an AV will range from $7,000 to $10,000 in year 2025, and that this amount will decrease to $5,000 in 2030, and to $3,000 in 2035. Jiang et al. (2015) in their market analysis for AVs outline a similar cost trajectory, with an AV price premium of $50,000 in 2015, decreasing to $10,000 around 2025, and $1,000 in 2030.

For shared autonomous vehicles (SAVs), cost is estimated in price per mile, and researchers have focused on estimating the cost savings of this new mode of travel. Burns (2013) found that the cost reductions of switching from a personal vehicle to a SAV could range from $0.18 to $0.34 per mile driven. Similarly, Morgan Stanley (2016) estimates that by 2030, the cost per mile in a SAV will be nearly 30% less than in a privately owned one. He asserts that the cost per mile driven in a shared vehicle will drop from $1.50 today to $0.50 in 2030 (Morgan Stanley, 2016). Childress et al. (2015) indicate that people will choose this mode since it is a more cost effective solution than owning a vehicle. *Figure 4* displays the average time costs for AVs and public transit as predicted by the models.

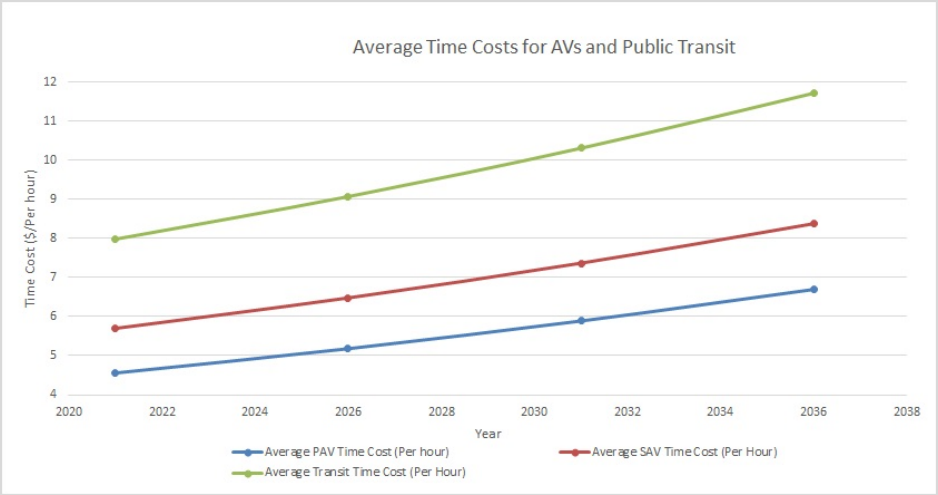


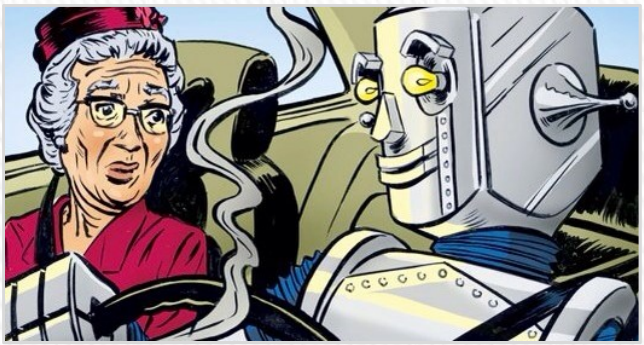
Figure 4: Average Time Costs for AVs and Public Transit. Costs can be thought of as more than just expenses, as time *savings* are one of the primary factors expected to drive AV adoption in the future.

4.2.4 ATTITUDES

In terms of attitudes, the perception of autonomous vehicles seems affected by issues of safety, security and control. Schoettle and Sivak (2014), in a survey in the US, UK, and Australia, found that the majority of the people had a positive perception of the technology, but were concerned about autonomous vehicles driving without human input and not reacting in the same way as a human driver would. This concern extended to all types of vehicles (personal, commercial, buses and taxis), and respondents stated that while they would like to have this technology in their vehicles, they would not pay extra for it (Schoettle et al., 2014).

Bansal et al. (2016) further investigated willingness to pay and possible adoption rates of these vehicles. On average, survey respondents stated that they would be willing to pay around $7,000 for a level 4 vehicle, and nearly 50% of the respondents demonstrated a willingness to buy one if their friends or neighbours decided to buy one as well. In terms of shared autonomous vehicles (SAV), more than 80% would not pay more for an SAV if the cost was higher than what current car share companies are charging (Bansal, 2016). Daziano, Sarrias and Leard (2016), however, point out that attitudes are widely dispersed; they find that demand is almost split evenly between high, modest and no demand, with a significant portion of respondents willing to pay more than $10,000 for automation, and others not willing to pay anything extra.

Fagnant and Kokelman (2015) have identified negative public perceptions as a potential delay on the implementation of AVs. Further issues raised include security (hackers and car-jackers) and privacy. Attitudes towards choosing AVs as a transport mode may also be influenced by the perception of whether time has been regained or not. Chen and Kockelman (2016) developed a mode choice model to compare the share of AVs against other modes of transport. It was found that when the perceived burden of traveling (value of traveler time (VOTT)) in an SAV is half as much as traveling in a private vehicle, the market share for SAVs is estimated to be 19.5%. On the other hand, when the burden of travel in an SAV is a fourth of that of a private vehicle, the market share for SAVs is 30.6% (Chen, 2016).



(LIN, 2014)

4.3.1 CONGESTION

Autonomous vehicles are most commonly viewed as having a positive impact on roadway congestion. The technology is anticipated to enable vehicles to travel more closely together, thereby allowing more of them to travel on a road at once. They will also increase efficiency by removing human response time. The magnitude of these benefits depend largely on the extent to which AVs have penetrated the market. Fagnant and Kockelman (2015) estimate that at a market penetration of less than 30%, congestion will be reduced by only 5%. At over 70% market penetration, congestion will decrease by 15%. Highways in particular would see capacity increases because of a lack of intersections or other road users such as pedestrians and cyclists. At a 90% market penetration, the effective road capacity is expected to double (Schrank et al., 2012).

However, the attractiveness of being able to engage in other activities (work or entertainment) while traveling may signal that people are willing to accept a longer commute. This contributes to a greater total VKT (vehicle kilometers travelled). The affordability, convenience, and accessibility of AVs may also induce demand as people may send their vehicle away empty to perform an errand or find free parking. As well, people who are unable to drive a conventional vehicle may make more trips by car than before. Thanks to AV technology (Anderson, 2016; Litman, 2016). SAVs, while reducing the overall number of vehicles on the road, are expected to increase VKT because empty vehicles will need to re-locate to pick up their next passenger (Fagnant & Kockelman, 2014). Bierstedt et al. (2014) suggest that at an AV market penetration of 25%, VKT will increase by 5-10%.

(HARLEY, 2016)

4.3.1 CONGESTION

To combat this increase in VKT, governments may need to introduce pricing strategies - especially if travel by AV becomes so affordable that it competes with public transit. A per kilometre, GPS-enabled user charge has been suggested as the most effective way to give users pricing signals to curb demand. Fishman (2016) recommends removing more fixed taxes like vehicle registration fees and fuel tax in favour of this more sensitive charge. The State of Tennessee's Senate recently passed legislation codifying automation levels and introducing a per mile tax. However, the charges are extremely low ($0.01 per mile tax on AVs with two axles and $0.026 per mile tax on AVs with more than two axles), and the intention of this legislation is to attract business to the region, not to curb congestion (Hearn, 2016). *Figure 5* shows the estimated travel time index per scenario. As adoption rates increase over time, congestion worsens until the 2030s when a pricing strategy, such as cordon pricing or an empty vehicle charge, comes into effect.

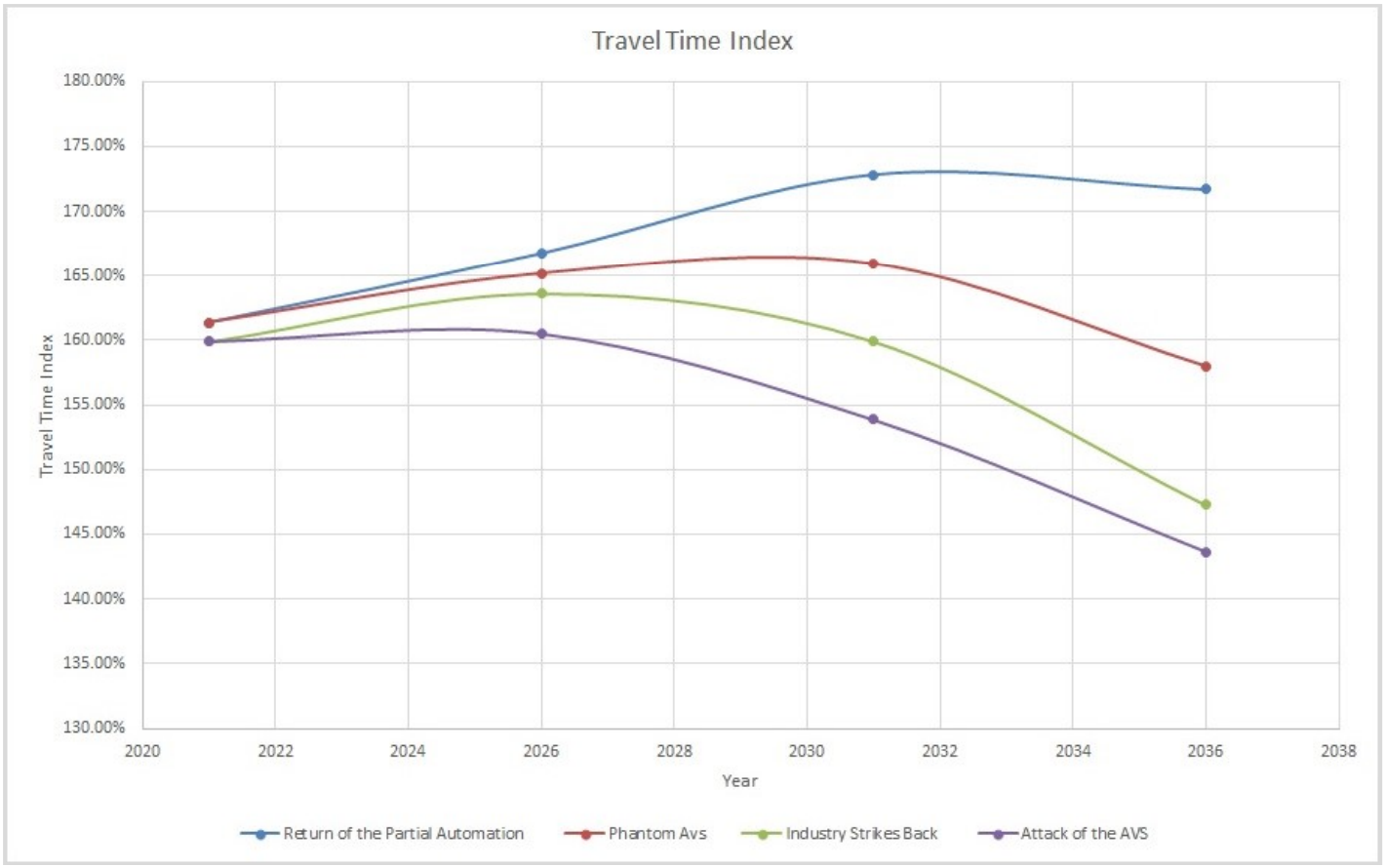


Figure 5: Travel Time Index. Travel Time Index values are the ratio of travel during peak congestion in comparison to free flow traffic. Depending on rates of adoption, AVs may actually reduce overall congestion in the long term. Early on however, AVs may increase congestion

(HUYNH, 2016)

4.3.2 ACCESSIBILITY

A major benefit of AV technology will be the fundamental change that it brings to transportation accessibility for people who are unable to operate a motor vehicle, including the elderly, people with disabilities, and youth. By 2030 AVs could significantly improve the quality of life for a projected 75,000 seniors with disabilities who face challenges using existing public transit in Toronto (Ticoll, 2015). Eighty percent of Canadian baby boomers are online, indicating that the majority of this population will be comfortable summoning an AV through a digital platform (Metrolinx, 2016). Reducing the reliance of these demographics on others to drive them will potentially provide cheaper and easier transportation compared to the alternatives that exist today (CAVCOE, 2015).

While AV technology holds the promise of enhanced mobility for these populations, it remains to be seen how regulatory and cost barriers will be overcome to ensure equitable access. In addition, the benefits of improved accessibility may not translate to people with mobility devices or in need of an attendant. The requirement for a specially-designed vehicle and personal support may mean some service continues to follow the para-transit model in place today.

4.3.3 LIABILITY

With the advent of AV technology the landscape of liability will inevitably change. Traditionally liability for automobiles has been associated with human/user error. However with AV technology, collisions are expected to be significantly less, and liability will shift to the product producer.

In order for product liability to exist the plaintiff must establish two things: first that the product sold to the defendant was defective, and second, the defect was indeed the cause of the plaintiff's injury (Funkhouser, 2013). In an AV, product liability may fall on the automaker, technology developer, or software designer. User maintenance or a failure of smart infrastructure from the municipality may also play a role and be held accountable.

What essentially will flow from the implementation of AV technology is a massive upheaval in the insurance industry, with the personal auto insurance sector shrinking, and replaced by commercial and product liability (KPMG, 2015). Policy makers, insurance companies, and manufacturers will need to sort through these issues through legislation and the courts of law, with semi-autonomous functions like parking assist offering the first test cases.

4.3.4 LAND USE

With the advent of AV technology, the way in which we use land could shift. People may find congested car travel more palatable and shy away from public transit. They may choose to live further away from their work for more affordable housing options, resulting in a more dispersed and potentially low-density land use pattern. However, particularly in a predominantly shared ownership model where parking demand is greatly reduced, the removal of off-street infrastructure could lead to a more built up environment with more intensified space (Anderson, 2016). A study that modeled SAVs in the City of Lisbon found that 80% of off-street parking could be removed (OECD/ITF, 2015). There is opportunity for the use of space in the public right of way to change as well. Roadway capacity, freed up through tighter flowing traffic and fewer collisions, could be reallocated to pedestrians and/or cyclists. On-street parking, if no longer required, could transition into pick-up and drop-off zones, and could continue to represent a significant source of revenue for the City through fee-per-use. The same study of Lisbon found that 210 football fields, or nearly 20% of the City's curb to curb street space, could be freed up from the elimination of unnecessary parking space resulting from the onset of AVs (OECD/ITF, 2015). *Figure 6* models the projected parking reductions anticipated to develop in each scenario. With higher AV adoption rates, there is a greater number of potentially freed parking spaces.

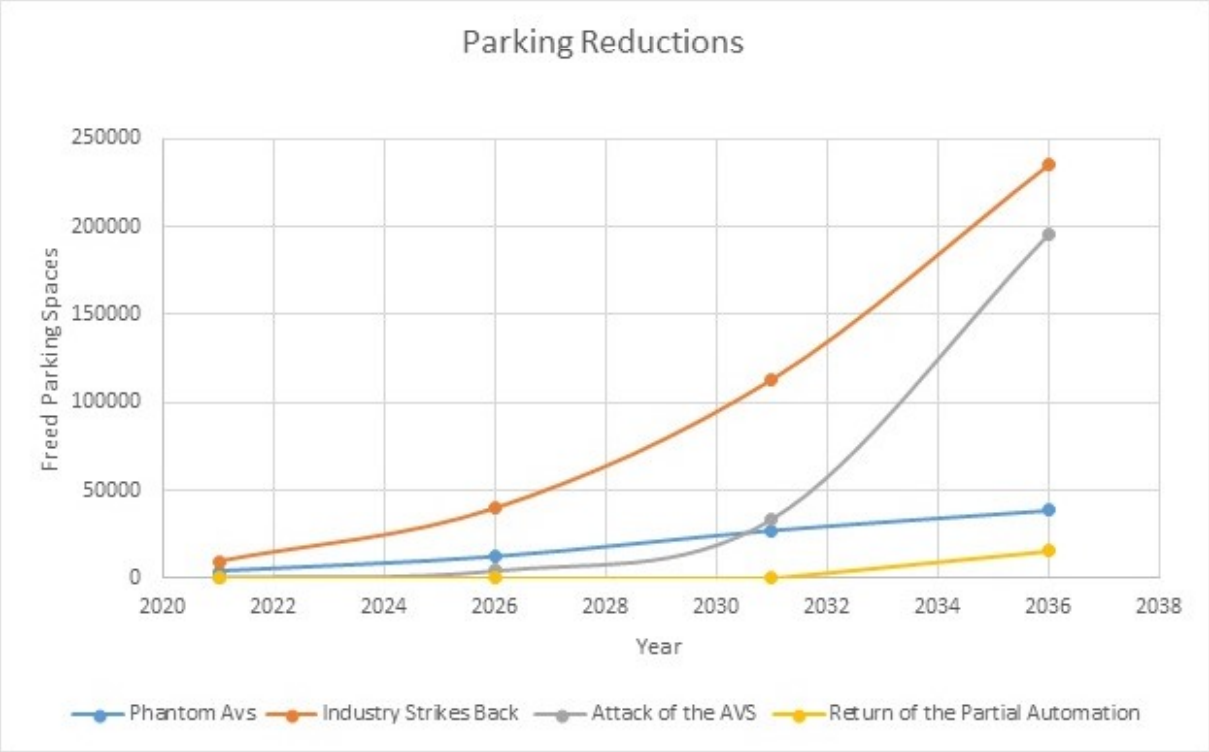


Figure 6: Parking Reductions. Significant reductions in parking may free up land for more valuable uses.

4.3.5 PRIVACY

Privacy has been identified as an important issue that could delay the deployment of AVs (Anderson, 2016). Information obtainable from an AV will include: trip data (origin, destination, route), derived data (frequent trips to Starbucks would indicate a love for coffee), data on activities performed in the AV, and data that passes through the AV's entertainment system (email, social media, movie choices, etc.) (Schoonmaker, 2016). Obviously of value to many commercial interests, such as car manufacturers, insurance companies and retailers, the information will also represent a powerful tool for governments actively engaged in sustainability and transportation planning. However, questions have been raised relating to consent, ownership, control, and disposal of this data, and there is a need for clear standards to be developed at the federal level (Fagnant et al, 2015).

Currently, applications on cell phones that use Location-Based Services (LBS) request consent, but most users accept the terms and conditions just to gain access to the mapping capabilities without a clear understanding of how their data are being used. The practice is industry-initiated, and not mandated (Schoonmaker, 2016). The U.S. Department of Transportation's (DOT's) recently-released *Federal Automated Vehicles Policy* (2016) describes best practices with regards to privacy. Data related to events such as collisions or malfunctions should be tracked, but meet the standards of privacy set by the manufacturers that are in line with consumer consent. The DOT also recommends that manufacturers' privacy policies ensure transparency, de-identification, accountability, and security. Although not mandatory as of yet, elements of this policy may be mandated in the future. While the US is moving in the direction of enhanced consumer privacy protection with the drafting of the Consumer Privacy Bill of Rights (not yet passed), the European Union has already committed to a strict policy with substantial consequences for non-compliance. The General Data Protection Regulation (GDPR) will go into effect on May 25, 2018 and will govern organizations in the EU.

(VENNGAGE, 2016)

(RICHLAND, 2016)

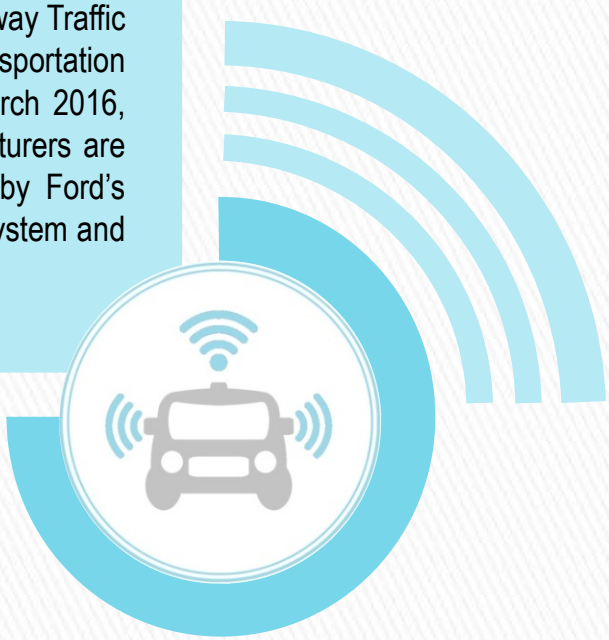
(MACON DAILY, 2016)

4.3.6 SECURITY

Autonomous vehicles have also been identified as vulnerable to cyberattacks and hacking (Litman, 2015). Currently, vehicles are designed with all computers (upwards of 100 in luxury models) connected through a central Control Area Network (CAN). Even critical messages are unencrypted and received without any verification that they are legitimate. In the past, the requirement to have physical access to this network was considered deterrent enough to guard against attacks, but as vehicles become more connected, they are increasingly vulnerable to remote attacks.

Already a number of projects have demonstrated that current vehicles' security can be compromised remotely through diagnostic equipment widely used by mechanics, and through the media player, keyless entry, bluetooth functionality, cellular modem and more. These capabilities offer opportunities for surveillance and theft (Checkoway et al., 2011; Valasek and Miller, 2015), and as more and more of a vehicle's safety-critical and navigational functions (steering, braking, adaptive cruise control, lane-keeping, etc) become automated, the vulnerability to attack increases.

The US Federal Bureau of Investigation (FBI), National Highway Traffic Safety Administration (NHTSA) and the Department of Transportation (DOT) released a joint public service announcement in March 2016, warning consumers of these increased risks. Car manufacturers are moving to address these issues, however, as evidenced by Ford's recent agreement with BlackBerry to develop an operating system and better security technology for its vehicles (Wall, 2016)



(CLEPA, 2016)

4.3.7 TRANSIT

The anticipated impacts of AVs on transit are mixed. Some studies suggest that buses will likely become unnecessary, but that mass-transit will remain viable and essential. For example, a model based in Lisbon found that in a system with high capacity public transit, it was possible to remove 65% of the vehicles on the road (including buses), replace the remainder with SAVs, and still provide the same level of service. Without a high capacity public transit system, only 23% of the vehicles could be removed (OECD/ITF, 2015). There are fears that SAVs may become priced so low that traditional transit will be unable to compete. A study from Columbia University estimated the cost of a privately-owned, conventional vehicle at $1.60 per mile, an SAV at $0.41 per mile, and a pod-sized, one to two person SAV at $0.15 per mile. While other studies anticipate slightly higher costs ($0.50 per mile), they still position SAVs as competitive with transit. *Figure 7* provides a cost comparison estimate between SAV, PAV, and public transit fares for the Attack of the AVs scenario. As time advances and adoption rates increase, AVs become more competitive with public transit and undergo a significant increase in modal share (as indicated by the circle size in the graph).

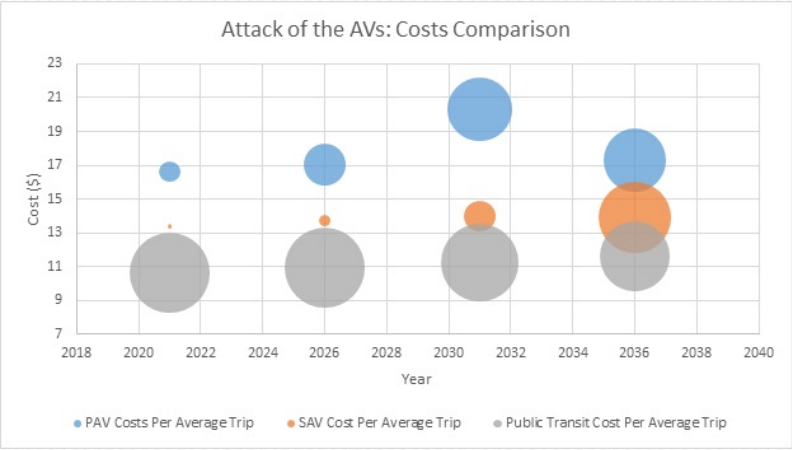


Figure 7: Attack of the AVs: Cost Comparison.

At higher prices ($1.65 per mile), research into ride-sharing behaviour suggests that individuals may increase their transit use, as the ability to occasionally access a vehicle allows them to give up private car ownership, but transit remains more cost-effective mode than an SAV (Childress et al, 2015).

4.3.8 FREIGHT

The same technologies used in personalized AVs can be applied to moving overland freight as well. Indeed, some mining companies already use automated trucks in controlled situations underground; for example, Rio Tinto has 53 self-driving trucks that have driven 2.4 million miles (Fagnant and Kockelman, 2015). Widespread adoption of this technology could increase fuel economy, decrease freight congestion, and lower the need for truck drivers (Fagnant and Kockelman, 2015). Currently, the number of hours that a truck driver may work in a day is highly regulated; automation would allow for the continuous movement of goods, in addition to reduced labour costs. The advent of much cheaper trucking could lead to an increase in VKT, as sections of the market are attracted away from transport by rail. This shift could have broad ramifications for the patterns of goods movement across the continent, as well as consequences for employment.

4.3.9 EMPLOYMENT

Autonomous vehicles are anticipated to have both positive and negative effects on employment, depending on the sector. Ticoll (2015) has identified three possible areas of influence. First, the technology's positive impact on the construction and technology industries will translate into more jobs. Second, positive gains may be seen in wholesale and retail trade, transportation, and public services due to increased efficiencies. Third, sectors such as automobile manufacturing, distribution, taxis and limousines, and insurance companies will likely experience severe economic and job losses. Ticoll further estimates percentages of gains or losses in terms of jobs according to industry sector. For example, he anticipates the construction industry will gain between 2% to 15% more jobs, but taxi and limousine services will lose between 50% to 90% of jobs (Ticoll, 2015).

(CANTENEUR 2015)

4.3.10 ENVIRONMENT

Research into the environmental impacts of AVs is mixed. A number of studies predict a decrease in vehicle emissions (GHG, CO, VOC, and others) (Anderson et al., 2016), even in spite of an increase in VKT (Fagnant and Kockelman, 2014). Researchers foresee a reduction in energy use of up to 80% from platooning, efficient traffic flow, light-weighting and ride-sharing. Others predict that VKT could double and overall energy use would therefore increase threefold as a result of increased accessibility, an increased number of trips, a shift away from public transit, longer commutes, empty trips for self-parking and self-fueling, and more luxurious vehicle use (Greenblatt and Shaheen, 2015).

Greenblatt and Shaheen (2015) argue it is likely that all of these trends will take place alongside each other, and with increasing fuel prices, a younger generation who drives less, and the growth of electric vehicles, the result will be a net decrease in energy consumption - even if the small, lightweight, shared, electric AVs that figure in the most positive forecasts do not materialize.

(JAFFER, 2015)

4.3.11 CONNECTED VEHICLES

It is important to remember that AVs are not the only new technology on the horizon; rather they will develop against a backdrop of other technology advances, one of which is connected vehicles. As already described in the *Technology* section of this report, connected vehicles will be able to communicate position, speed, steering wheel position and braking activity to each other using either short (DSRC) and/or long range (LTE) communications. A study using a model of Toronto traffic information found that vehicle connectivity alone can have considerable safety, environmental and congestion benefits (Olia, A., Abdelgawad, H., Abdulhai, B., & Razavi, S.N., 2016). In another study, the majority of experts surveyed predicted that all new vehicles sold in the US would have connected, vehicle-to-vehicle capabilities by 2020 (Brugeman, 2016).

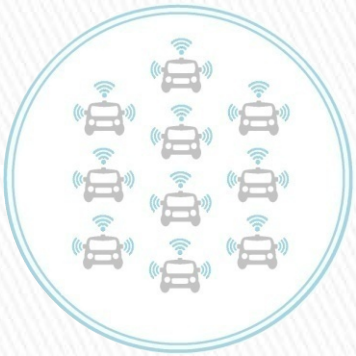
4.3.12 ON-DEMAND, SHARED MOBILITY

Another trend that will continue, independent of the development of AVs, is that of on-demand, shared mobility. Although it is likely that once AVs are released, the on-demand model of ownership will be popular, the growth of car-sharing and the explosion of Uber have demonstrated that this format is feasible in dense urban centres - even without removing the driver from the equation. While published ride-sharing studies are rare, car-sharing has been associated with increased walking and transit use, reduced VKT and lower greenhouse gas emissions. In addition, car-sharing vehicles have been found to remove 9 to 13 vehicles from the road on average due to users selling their personal vehicles or delaying in purchasing a new one (Greenblatt and Shaheen, 2015). As already noted, AVs are expected to reduce the cost of operating an on-demand mobility service, thus allowing these networks to expand into the suburbs and become a viable transportation alternative for more people.

5.0 HINGE POINT HIGHLIGHTS

5.0 HINGE POINT HIGHLIGHTS

In our scenarios, key decision moments for government are associated with the following issues. Decisions of how to act or whether to act influence the unfolding of events in dramatic ways as the scenarios have proved. These moments are hinge points, highlighted here for the careful consideration of policy and decision-makers.



REGULATING PARTIAL AUTOMATION

CITY OF TORONTO AND PROVINCE OF ONTARIO

Partial automation (levels 3 and 4) potentially present safety risks because of the need for the driver to continue being alert, despite not actively being engaged in the driving task. Governments may need to ban the use of partially autonomous modes on city streets, restricting them to closed access highways, to limit inattentive driving near vulnerable road users like pedestrians and cyclists. Enforcement would require vehicles to indicate externally when the autonomous driving mode has been enabled.

DATA PRIVACY AND VEHICLE SECURITY

PROVINCE OF ONTARIO AND FEDERAL GOVERNMENT

Standards that address consent, collection, ownership, sharing and disposal of data may need to be implemented to ensure users' privacy is respected. Likely, this data will be collected by private companies, but the government may stipulate that it have access to aggregate, anonymous data for transportation planning purposes. Vehicle safety certifications may also need to be updated to guard against cyberattacks. Regular vehicle security updates may be required.

5.0 HINGE POINT HIGHLIGHTS

PRICING STRATEGIES

CITY OF TORONTO & OTHER MUNICIPALITIES AND PROVINCE OF ONTARIO

If AVs are affordable enough for the average consumer to purchase, governments may need to implement a pricing strategy to discourage empty vehicle travel, slow the growth of congestion and induced demand, and encourage the use of transit and SAVs. *Figure 8* demonstrates how the introduction of a pricing strategy can impact the projected number of PAV and SAV VKT, fare costs, and operating costs. As shared mobility grows and the number of cars on the road declines, the City may need to move proactively to reclaim right-of-way space for other uses.

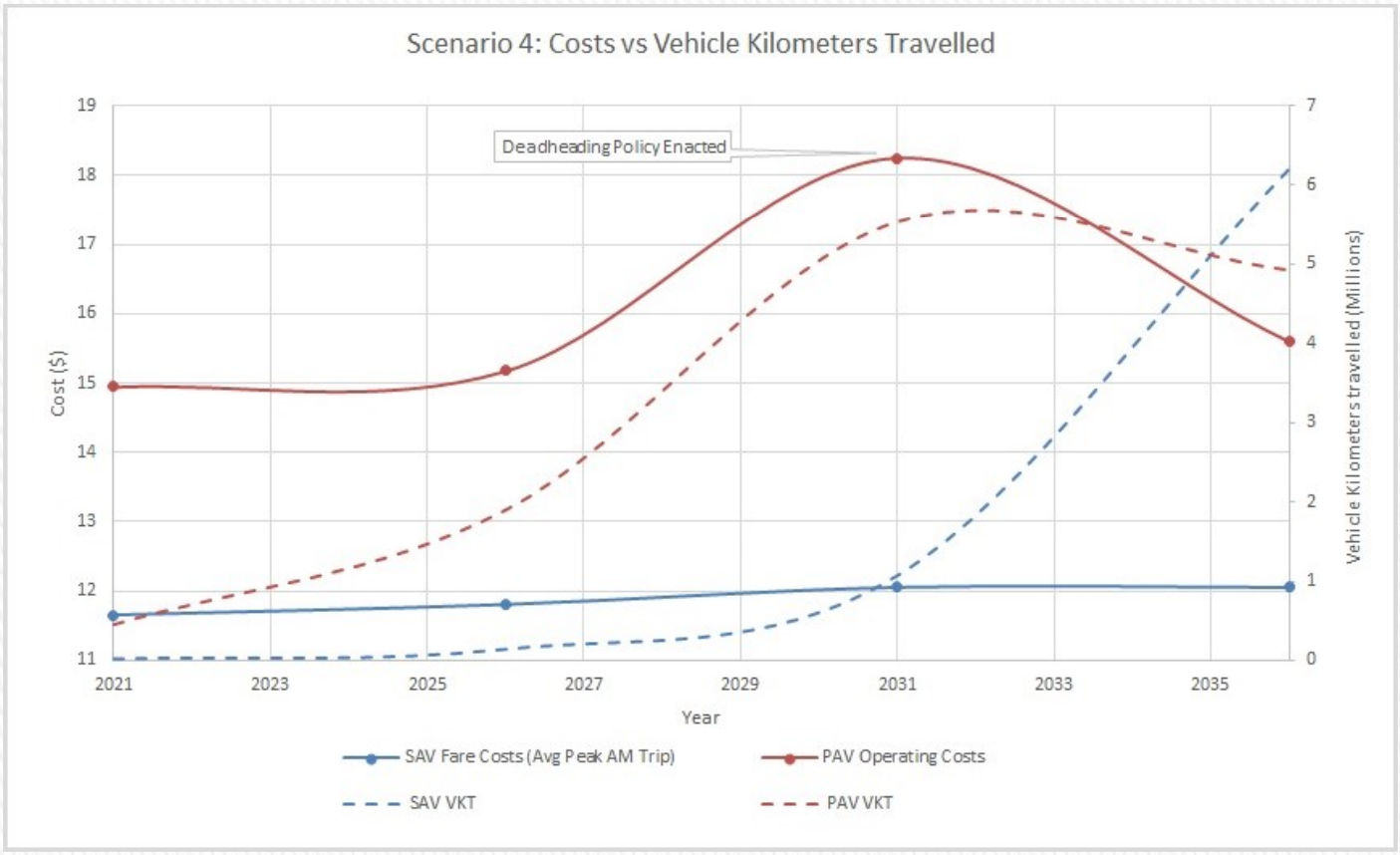


Figure 8: Scenario 4: Costs vs Vehicle Kilometres Travelled. The impacts of empty vehicle pricing on private AV vehicle kilometers travelled demonstrates the importance of proactive policy in managing AVs.

5.0 HINGE POINT HIGHLIGHTS

TRANSIT

CITY OF TORONTO & OTHER MUNICIPALITIES AND PROVINCE OF ONTARIO

Automation may make shared, on-demand mobility very affordable. While higher order transit will continue to be offered (particularly if a pricing strategy is introduced), lower ridership routes may no longer be feasible in the face of a fleet of SAVs. The public sector may be involved in developing and operating such a fleet or alternatively, SAVs may be left to private sector, much like taxis are today. In the latter case, the government may need to ensure that transit coverage targets are still met.

ACCESSIBILITY

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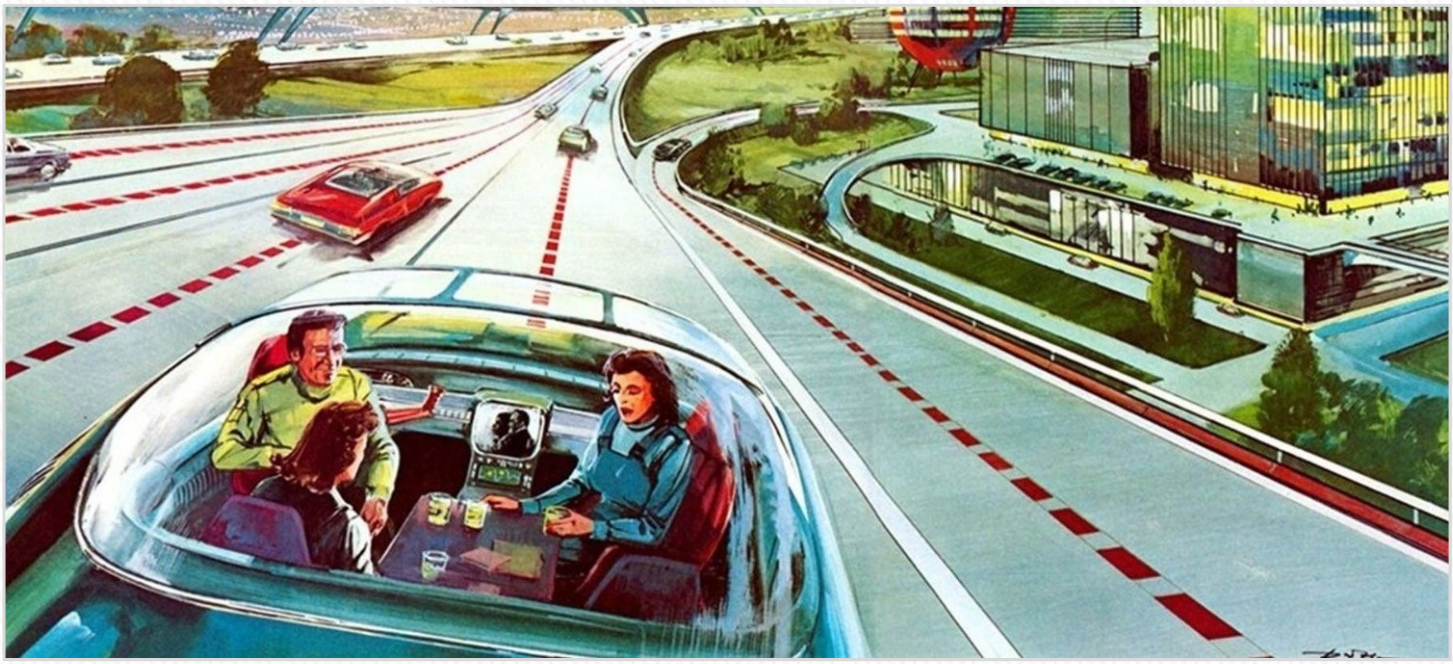
As methods of mobility shift, it will be necessary to ensure that new fleets are accessible to a wide diversity of users, including seniors and people with disabilities. A deeper understanding of how users will interface with the technology is needed. Regulations may need to be put in place to ensure that unnecessary limitations (ie. visual, auditory, language) are avoided, and that a certain percentage of SAVs are physically adapted to offer barrier-free access. As well, with the advent of full automation, licensing will need to be re-visited to permit non-licensed users to reap mobility benefits. Consideration will need to be given to travel by unaccompanied children, and to individuals who require the assistance of an attendant.

ATTITUDES

CITY OF TORONTO & OTHER MUNICIPALITIES AND PROVINCE OF ONTARIO

The public's comfort level with AVs will be related to the availability of occasions for them to interact with the technology in a positive way. As automation improves, the AV policy in Ontario could begin to shift away from a focus on testing vehicle technology to testing the interface between AVs, the built environment, and people. Opportunities for the public to familiarize themselves gradually with AVs could be offered, such as funding research and exhibiting the results, and supporting pilot projects along a specific route or within a controlled area.

CONCLUDING THOUGHTS



(FRANZEN, 2015)

While the future of urban mobility influenced by the adoption of AVs remains uncertain, the potential for positive change is clear. Realizing it, however, will require thoughtful action at critical moments. By constructing four plausible and distinct scenarios, we sought to uncover these decision points and critically explore the role of various actors in shaping the future of AVs in the GTHA. We hope this report will help the City of Toronto navigate the road ahead, and seize this rare opportunity to capture the greatest possible benefit from what promises to be a paradigm-shifting technology.

6.0 APPENDIX

6.0 APPENDIX – DATA AND ASSUMPTIONS UTILIZED FOR MODELS

Variable	Value	Calculation	Source
Lane Capacity - Speed Elasticity	-0.0146	Calculated from HDR values. Elasticity of congested roadway speed relative to the ratio of volume to capacity.	(Metrolinx, 2008)
Road Capacity (GTHA)	69562905	Calculated from Metrolinx HDR Report.	(Metrolinx, 2008)
Road Capacity Demand Elasticity	0.73		(Cervero, 2003)
Road Capacity Growth Rate	0.006131	Calculated from the 2006 growth rate, and projected growth rates according to the "business as usual" model used in the draft regional transit plan by Metrolinx.	(Metrolinx)
TTC Fare Growth Rate	0.010177	Based on data from 2012 to 2016.	(TTC, 2016)
GTHA Commuting Population Growth Rate	0.009673	Original data from Metrolinx HDR report.	(Metrolinx, 2008)
Vehicle Kilometers Travelled 2016 (Peak AM)	36666487	Calculated from Metrolinx HDR report.	(Metrolinx, 2008)
Vehicle Kilometers Travelled Trend Growth Rate (2016-2030)	0.016521	Quest Project: Projections by Eric J. Miller.	(Miller, 2006)
Vehicle Kilometers Travelled Trend Growth Rate (2030+)	0.007288	Quest Project: Projections by Eric J. Miller.	(Miller, 2006)
Average Trip Length in the GTHA	11.4km	Calculated from Metrolinx HDR Report.	(Metrolinx, 2008)
Time Value per Hour	$20.30/h	Calculated from 2011 National Housing Survey.	(Statistics Canada, 2011)
Vehicle Traveler Time Value	50%	Victoria Transport Policy Institute transportation cost and benefit analysis techniques, estimates and implications.	(Victoria Transport Policy Institute, 2016)
Transit Traveler Time Value	35%		
SAV Time Value	25%	Assumption	
PAV Time Value	20%	Assumption	
Average Free Flow GTHA Speed	74km/h	Calculated from Metrolinx HDR Report	(Metrolinx, 2008)
Congested Peak AM GTHA Speed	Variable	Calculated using Peak AM GTHA speed, the current volume to capacity ratio (determined by VKT), lane capacity, and speed elasticity measures.	
Number of SAVs	Variable	Values from Fagnant & Kockleman (2014)	(Fagnant & Kockleman, 2014a)
SAV High Costs	$0.679/km	Raw operational costs based on a conservative $90,000 price premium, and the average operation cost of a 'Mini' class car in Toronto. SAVs are assumed to have an average operative life of 300,000km	(Canadian Automotive Association, 2016)
SAV Low Costs	$0.573/km	Raw operational costs based on a conservative $50,000 price premium, and the average operation cost of a 'Mini' class car in Toronto.	(Canadian Automotive Association, 2016)
PAV High Costs	$0.997/km	Raw operational costs based on a conservative $90,000 price premium, and the average operation cost of a Full Size class car in Toronto.	(Canadian Automotive Association, 2016)
PAV Low Costs	$0.847/km	Raw operational costs based on a very conservative $50,000 price premium, and the average operation cost of a Full Size class car in Toronto.	(Canadian Automotive Association, 2016)
SAV Fares	Operational Cost*1.2+1.5	Based on Ubers current pricing practices: 20% of ride fare + $1.50 "Safe Ride" fee.	(Uber, 2016)
Maximum Adoption Rate	20%	Identified by Tod Litman who estimated his adoption rates based on vehicle turnover rates and the automotive industries past behaviors regarding other technologies (such as automatic transmission and airbags).	(Litman, 2016)

7.0 REFERENCES

7.0 REFERENCES

Anderson, M., Karla, N., Stanley, K., Sorensen, P., Samaras, C., Oluwatobi,O. (2016). *Autonomous Vehicle Technology: Guide for Policymakers*. Rand Corporation.

Bansal, P., Kockelman, K. M., & Singh, A. (2016). Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. *Transportation Research Part C: Emerging Technologies*, *67*, 1-14

Bierstedt, J., Gooze, A., Gray, C., Peterman, J., Raykin, L., & Walters, J. (2014). Effects of Next-Generation Vehicles on Travel Demand and Highway Capacity. FP Think. Accessed: http://orfe.princeton.edu/~alaink/Papers/FP_NextGenVehicleWhitePaper012414.pdf

Burns, L., Jordan, W., & Scarborough, B. (2013). Transforming Personal Mobility. The Earth Institute, Columbia University, New York.

Brugeman, V., Wallace, R., Cregger, J., Smith, M., & Tansil, W. (2016). *EXPERT OPINION FORECAST OF CONNECTED VEHICLE TECHNOLOGY*. Retrieved from https://itswc.confex.com/itswc/AM2013/webprogram/Paper11480.html

Checkoway, S., McCoy, D., Kantor, B., Anderson, D., Shacham, H., Savage, S., Koscher, K., Czeskis, A., Roesner, F., & Kohno, T. (2011). Comprehensive experimental analyses of automotive attack surfaces. San Francisco: Proceedings of the 20th USENIX Conference on Security. Accessed: http://dl.acm.org/citation.cfm?id=2028073

Chen, T. D. (2015). *Management of a shared, autonomous, electric vehicle fleet: vehicle choice, charging infrastructure & pricing strategies* (Doctoral dissertation).

Childress, S., Nichols, B., Charlton, B., & Coe, S. (2015). Using an Activity-Based Model to Explore the Potential Impacts of Automated Vehicles. *Transportation Research Record: Journal Of The Transportation Research Board*, *2493*, 99-106. http://dx.doi.org/10.3141/2493-11

Daziano, R., Sarrias, M., & Leard, B. (2016). Are consumers willing to pay to let cars drive for them? Analyzing response to autonomous vehicles. Washington: Resources for the Future. Accessed: http://www.rff.org/files/document/file/RFF-DP-16-35.pdf

Dresner, K., & Stone, P. (2008). A multiagent approach to autonomous intersection management. *Journal of artificial intelligence r research*, *31*, 591-656.

Fagnant, D. J., & Kockelman, K. M. (2014a). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. *Transportation Research Part C: Emerging Technologies*, 40, 1-13. Chicago

Fagnant, D. J., & Kockelman, K. (2014b). Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. In *Transportation Research Board 93rd Annual Meeting* (No. 14-1281).

Fishman, E. (2016). Road User Pricing: Driverless cars, congestion and policy responses. Paper presented at the Australasian Transport Research Forum. Melbourne: ResearchGate. Accessed: https://www.researchgate.net/publication/308647720_Road_User_Pricing_Driverless_cars_congestion_and_policy_responses

Federal Bureau of Investigation, Department of Transportation, & National Highway Traffic Safety Administration. (2016). Motor Vehicles Increasingly Vulnerable to Remote Exploits. Public Service Announcement. Accessed: https://www.ic3.gov/media/2016/160317.aspx

Funkhouser, K. Paving the Road Ahead: Autonomous Vehicles, Products, Liability, and the Need for a New Approach. (2013). University of Utah.

Greenblatt, J. & Shaheen, S. (2015). Automated Vehicles, On-Demand Mobility, and Environmental Impacts. *Current Sustainable/Renewable Energy Reports*, *2*(3), 74-81. http://dx.doi.org/10.1007/s40518-015-0038-5

Hearn, S. (2016). Senate passes legislation regulating autonomous vehicle use, tax structure. *Brentwood Homepage.* Accessed: http://brentwoodhomepage.com/senate-passes-legislation-regulating-autonomous-vehicle-use-tax-structure/

H. S. (2014). Emerging Technologies: Autonomous Cars-Not If, But When. *IHS Automotive study, http://press. ihs. com/press-release/automotive/self-driving-cars-moving-industrys-drivers-seat*.

Jian, T. & Petrovic, S. (2015). *Self-Driving Cars: Disruptive or Incremental?* (pp. 3-22). Retrieved from http://cet.berkeley.edu/wp-content/uploads/Self-Driving-Cars.pdf

KPMG. (2015). Marketplace of change: Automobile insurance in the era of autonomous vehicles.

Lambert, F. (2016). *Understanding the fatal Tesla Accident on Autopilot and the NHTSA Probe.* Electrek. Retrieved from https://electrek.co/2016/07/01/understanding-fatal-tesla-accident-autopilot-nhtsa-probe/.

Litman, T. (2014). Autonomous Vehicle Implementation Predictions. *Victoria Transport Policy Institute*, *28*.

Lu, N., Cheng, N., Zhang, N., Shen, X., & Mark, J. W. (2014). Connected vehicles: Solutions and challenges. *IEEE internet of things journal*, *1*(4), 289-299.

7.0 REFERENCES

Morgan Stanley. (2016, October 19). *Ideas*. Retrieved from http://www.morganstanley.com/ideas/car-of-future-is-autonomous-electric-shared-mobility

Ministry of Transportation. (2016). *Automated Vehicles - Driving Innovation in Ontario*. Toronto: Queen's Printer for Ontario. Retrieved from http://www.mto.gov.on.ca/english/vehicles/automated-vehicles.shtml

Metrolinx. (2008). *Costs of road congestion in the greater Toronto and Halimton Area: Impact and cost benefit analysis of the Metrolinx draft regional plan.* HDR Corporation, Toronto, Government of Ontario.

Metrolinx. (2016). New Mobility Background Paper: Technical Paper 4 to support the *Discussion Paper for the Next Regional Transportation Plan.*

Miller, E. (2006). The Quest Project: A modified version of the gta model travel demand forecasting model system. University of Toronto

National Association of City Transportation Officials. (2016). Policy Statement on Automated Vehicles. Retrieved from: http://nacto.org/wp-content/uploads/2016/06/NACTO-Policy-Automated-Vehicles-201606.pdf

Nordhoff, S., van Arem, B., & Happee, R. (2016). A Conceptual Model to Explain, Predict, and Improve 2 User Acceptance of Driverless Vehicles 3. In *Transportation Research Board 95th Annual Meeting* (No. 16-5526).

Olia, A., Abdelgawad, H., Abdulhai, B., & Razavi, S. N. (2016;2015;). Assessing the potential impacts of Connected vehicles: Mobility, environmental, and safety perspectives. Journal of Intelligent Transportation Systems, 20(3), 229-15.

OECD/International Transport Forum (ITF). (2015). Urban Mobility System Upgrade: How shared self-driving cars could change city traffic. Accessed: http://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf

Prentice, B. (2016). *Gartner Says Full Autonomy May Not be Possible or Desirable in Smart Machines*. Gartner. Retrieved from http://www.gartner.com/newsroom/id/3493717

Schoettle, B., & Sivak, M. (2014). *A survey of public opinion about autonomous and self-driving vehicles in the US, the UK, and Australia* (No. UMTRI-2014-21).

Schoemaker, P. J. H. (1995). Scenario planning: A tool for strategic thinking. *Sloan Management Review, 36*(2), 25.

Schoonmaker, J. (2016). Proactive privacy for a driverless age. *Information & Communications Technology Law, 25*(2), 96-128.

Shelley Row (2013), "The Future of Transportation: Connected Vehicles to Driverless Vehicles…What Does It Mean To Me?" ITE Journal (www.ite.org), Vol. 83, No. 10, pp. 24-25.

Shen, S. (2016). Quantifying drivers' responses to failures of semi-autonomous vehicle systems. ProQuest Dissertations Publishing.

Society of Automotive Engineers International (SAE),. (2014). *AUTOMATED DRIVING LEVELS OF DRIVING AUTOMATION ARE DEFINED IN NEW SAE INTERNATIONAL STANDARD J3016*. Retrieved from http://www.sae.org/misc/pdfs/automated_driving.pdf

Ticoll, D. (2015). *Driving Changes: Automated Vehicles in Toronto*. Toronto: University of Toronto.

U.S. Department of Transportation,. (2016). *Federal Automated Vehicles Policy - Accelerating the Next Revolution In Roadway Safety*. National Highway Traffic Safety Administration.

Valasek, C. & Miller, C. (2015). Remote Exploitation of an Unaltered Passenger Vehicle: Technical White Paper. IOActive. Accessed: http://www.ioactive.com/pdfs/IOActive_Remote_Car_Hacking.pdf

Van der Heijden, K. (2005). *Scenarios: The art of strategic conversation.* Toronto: John Wiley & Sons.

Victoria Transport Policy Institute. *(2016). Transportation Cost and Benefit Analysis Techniques, Estimates and Implications, 2nd Edition*

Wall, J. (2016). BlackBerry Inks Agreement with Ford to Accelerate Cars of the Future. *Inside BlackBerry.* Accessed: http://blogs.blackberry.com/2016/10/blackberry-inks-agreement-with-ford-to-accelerate-cars-of-the-future/

7.0 REFERENCES

IMAGE CREDITS:

C3 Group. (2014). *V2I.* [Digital Image]. Retrieved from http://www.cthreereport.com/v2v-v2i-and-law-enforcement-the-new-robocop/.

Canteneur, P. (2015). *Mass Adoption*. [Digital Image]. Retrieved from http://www.atelier.net/en/trends/articles/autonomous-vehicles-mass-adoption-predicted-2050_436634.

CLEPA. (2016). *Autonomous Vehicles.* [Digital Image]. Retrieved from http://clepa.eu/mediaroom/autonomous-vehicles-will-drive-change-auto-manufacturing-insurance/.

Franzen, C. (2015). *Autonomous Vehicle Future*. [Digital Image]. Retrieved from http://www.popularmechanics.com/cars/a13942/3-reasons-why-driverless-cars-arent-ready-for-the-road/.

Harley, M. (2016) *Congestion*. [Digital Image]. Retrieved from http://www.motorpressguild.org/autonomous-vehicles-are-going-to-save-us-from-standing-still/

Howard, B. (2014). *V2V*. [Digital Image]. Retrieved from http://www.extremetech.com/extreme/176093-v2v-what-are-vehicle-to-vehicle-communications-and-how-does-it-work.

Huynh, T. (2016). *Google Self-Driving Car.* [Digital Image]. Retrieved from http://www.techradar.com/news/car-tech/google-self-driving-car-everything-you-need-to-know-1321548.

Jaffer, N. (2016). *Toronto.* [Digital Image]. Retrieved from http://www.moneysense.ca/spend/real-estate/best-deals-in-real-estate-2016-torontos-top-neighbourhoods/.

Kilcarr, S. (2016). *Self-Driving Cars*. [Digital Image]. Retrieved from http://fleetowner.com/blog/road-autonomy-may-be-paved-distraction.

Lavrinc, D. (2013). *Hands-Free.* [Digital Image]. Retrieved from https://www.wired.com/2013/06/nhtsa-autonomous-vehicles/.

Lin, P. (2014). *The Robot Car of Tomorrow*. [Digital Image]. Retrieved from https://www.wired.com/2014/05/the-robot-car-of-tomorrow-might-just-be-programmed-to-hit-you/.

Macon Daily. (2016). *AV Driver*. [Digital Image]. Retrieved from http://macondaily.com/are-the-cities-of-america-ready-for-autonomous-vehicles-and-vice-versa/.

Ministry of Energy and Infrastructure, Ministry of Natural Resources, & Ministry of Municipal Affairs and Housing. (2016). *Greater Golden Horseshoe*. [Digital Image]. Retrieved from http://www.placestogrow.ca/index.php?option=com_content&task=view&id=9.

RAND Corporation. (2016). *Autonomous Vehicle Technology*.[Digital Image]. Retrieved from http://www.rand.org/pubs/research_reports/RR443-2.html.

Richland, J. (2016). *Google Self-Driving Cars*. [Digital Image]. Retrieved from http://healthaffairs.org/blog/2016/03/04/steering-autonomous-vehicle-policy-the-role-of-public-health/.

Urban Toronto. (2016). *Toronto Harbour*. [Digital Image]. Retrieved from http://urbantoronto.ca/news/2016/03/photo-day-toronto-blue.

Vanderbilt, T. (2012). *AV Technology*. [Digital Image]. Retrieved from https://www.wired.com/2012/01/ff_autonomouscars/.

Venngage. (2016). *Autonomous Cars*. [Digital Image]. Retrieved from https://infograph.venngage.com/p/97547/autonomous-cars-infographic-group-work.