Forecasting the Outlook for Automated Vehicles in the Greater Toronto and Hamilton Area using a 2016 Consumer Survey

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TRANSFORM

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Overview

Automated vehicles may dramatically transform urban travel. However, the implications of automated vehicles and how consumers will adopt and use automated vehicles remains poorly understood. Using a consumer demand survey across the Greater Toronto and Hamilton Area (GTHA), this report seeks to understand the conditions under which consumers will adopt and use autonomous (level 5) or fully self-driving vehicles in the GTHA. Future travel behavior changes, mode share, and vehicle market shares are explored and forecasted based on several potential alternative futures.

Findings suggest that several demographic, household, and contextual factors are associated with the uptake of automated vehicles based on both privately owned and shared ownership models. These models focus on passenger travel and do not include the prospect of on-demand delivery of consumer products and services facilitated by automated vehicles. Key predictors of AV adoption and use identified by this study include: age-related effects (younger individuals are more interested in AVs), land use-related effects (those living in more urban neighborhoods are more interested in AVs), information-based effects (those who already know about AVs are more likely to purchase and use an AV), and prices (the cost of using on-demand shared AVs per km or the price premium of owning PAVs relative to conventional cars).

Scenario-based forecasts illustrating ten, thirty, and fifty-year time horizons explore possible futures using available data from the 2016 Automated Vehicle Consumer Survey. Future scenarios are constructed by focusing on changes in demographics (future residents adopt preferences similar to current younger survey participants under 35), changes in land use patterns (increasing urban density over time), and changes in residents' knowledge of AVs (future residents' preferences increasingly mirror those of the most informed survey participants). Results suggest that based on current preferences, private automated vehicles could represent approximately half of new vehicle sales if the premium on the vehicle is $1,000 or less (relative to conventional non-automated vehicles). Whereas the market share of AVs is expected to be less than five percent if the price premium exceeds $15,000.

Forecasts suggest that on-demand shared autonomous vehicles are likely to comprise of less than one percent of total mode share based on the existing and foreseeable preferences but would be expected to be used (regardless of frequency) by 77% percent of 18 to 75-year olds in the GTHA at a price of $0.50 per kilometer. In short, while many could use shared autonomous vehicles, these vehicles appear to be used, on average, for less than one out of every one-hundred trips. As such, these forecasts do not provide strong evidence that automated vehicles will lead to a reduction in personal car use based on current market interest. Unless consumers' willingness to pay increases dramatically, the price of technology decreases (to even less than $0.50 per kilometer), or policies that promote on-demand shared autonomous vehicles are implemented, the mode share for SAVs will remain less than one percent (on average, less than one trip per person per month). This report can provide guidance to planning initiatives in the Greater Toronto and Hamilton Area to evaluate the medium and long term policy, programming, and investment decisions in response to the emergence of automated vehicles.

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1.0 Background

The stakes are high in understanding how automated vehicles may transform urban travel. They are no longer confined to the realm of science fiction; the technology is quickly approaching the point at which it will be made available to the public. Industry experts predict that fully autonomous vehicles will penetrate the consumer market within the next fifteen years (Litman, 2017). Corporations such as Google, Uber, Tesla, Toyota, and General Motors have heavily invested in autonomous vehicle technology (Muoio, 2016); many of these companies are already testing their autonomous vehicles on city roads around the world. But the broader implications of this technology on society, cities, and the environment is poorly understood – leading to little clarity in public policy design for shaping this privately-produced technology for a collective public good.

There is much uncertainty in how this technology will be owned, used, and shaped by the public. Several key issues are highlighted below and evidence related to each of these questions continues to emerge almost daily.

Ownership - It remains unclear whether automated vehicles will be owned by individuals (private automated vehicles) or whether shared autonomous vehicles (SAVs) will be used by consumers like taxi trips or technology-enabled mobility products (e.g. Uber or Lyft).

Use - It is not clear whether automated vehicles are likely to induce users to travel further, take more trips, abandon public transit and walking, or not lead to a noticeable change in their travel behavior. Alternately, transportation system users could forego vehicle ownership and instead use shared driverless cars to augment public transit use and active travel.

Public Policy Implications - The role of public policy remains to be seen as automated vehicles emerge in the market. Public policy could either encourage or discourage the adoption of AVs. Implementing policies may be monumental in determining how this technology could be shaped to maximize societal benefits while mitigating negative impacts.

These sources of uncertainty have enormous implications for the transportation system and for what types of impacts the public might begin to expect from public policymaking. Automated vehicles could yield enormous benefits, from congestion reduction, fewer greenhouse gas emissions, safer streets, and more reliable travel conditions. According to Fagnant and Kockelman (2015), benefits from safety improvements, reduced travel times, fuel savings, and parking savings are expected to represent $2,000 per new automated vehicle on the road and are expected to double when automated vehicles become a majority share of the vehicle fleet. But they likewise could erode the market share of public transit, threaten the long-term financial outlook of public transit operators (most notably in suburban and rural contexts), and lead to urban sprawl. Harnessing the positive elements of automated vehicles through policy action while limiting the negative consequences hinges on understanding how consumers are likely to adopt and use this new technology. Visions of shared autonomous vehicles or privately-held automated vehicles may lead to significant differences in the individual and collective benefits accruing from automated vehicles.

1.1 What are Automated Vehicles?

Automated Vehicles (AVs) cannot be categorized as one type of vehicle. Rather, automated vehicles vary in how many automated features they have that replace or complement the human driver. The level of automation in a vehicle is typically ranked using a five-point scale that ranges from no automation (level 0) to fully autonomous (level 5) as shown in *Figure 1* (Society of Automotive Engineers, 2014). Automated vehicles use a combination of sensors, Light Detection and Ranging (LIDAR), and radar, to perform the functions of driving. Communications between AVs and infrastructure (vehicle-to-infrastructure or V2I) and AVs and other connected vehicles (vehicle-to-vehicle or V2V) operate through dedicated short range communications (DSRC) or lite range cellular (LITE). One example of a highly-automated vehicle is the Google Car; the company's prototype vehicles have accumulated over 2 million miles on city streets ever since testing began in 2009 (Google, 2016). But fully autonomous vehicles (Level 5) are still being developed and would represent the most significant change whereby there would no longer be any role for the human driver in accomplishing safety-critical functions (in contrast to Level 4 and below).

Figure 1: Levels of Automation

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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1.2 Brief Background on Consumer Interest in AVs

Some studies have already explored consumer adoption and use of both privately-owned and on-demand shared AVs, but to date no study has focused on estimating consumer preferences and travel behaviour responses within the Greater Toronto and Hamilton Area. These studies highlight the importance of understanding the relative balance of interest in either privately-owned AVs or on-demand shared AVs. Similarly, the rate of adoption, outlook for additional travel, and consistency with broader policy objectives are of concern.

Studies on consumer interest in AVs have found that consumers who drive frequently over long distances (Kyriakidis et al., 2015; Krueger, Rashidi, & Rose, 2016; Robertson, Meister, & Vanlaar, 2016), who are familiar with automated vehicle technology (Schoettle & Sivak, 2014; Kyriakidis et al. 2015), live in urban areas (Bansal, Kockelman, and Singh, 2016; Lavieri et al., 2017), and who are technologically-savvy (Bansal, Kockelman, & Singh, 2016; Zmud, Sener & Wagner, 2016; Lavieri et al., 2017) are more willing to adopt AVs. For example, Schoettle and Sivak (2014) found consumers generally perceive automated vehicles positively. Studies suggest that AVs are likely to be adopted by younger age groups and those with more discretionary income, but not all studies lead to the same conclusions. Overall, those interested in PAVs and SAVs appear to share many characteristics, but shifts from current travel behaviour are unclear (Zmud, Sener & Wagner, 2016; Bansal, Kockelman, & Singh, 2016; Krueger, Rashidi, & Rose, 2016; Lavieri et al., 2017; Deloitte, 2016; Bansal and Kockelman, 2017).

1.3 Research Gaps and Opportunities

While evidence is emerging, there is still much speculation about the future of automated vehicles. Policymakers must nevertheless grapple with the likelihood of alternate futures, their implications, and what policy actions are necessary to manage such a technology in a way to improve broader social and environmental objectives. There is a significant need for research to disentangle the hype to inform policy as to how actual people are likely to respond to the new technology. Given the unique characteristics of different regions, it is important to understand the specific characteristics of Greater Toronto and Hamilton Area (GTHA) residents rather than strictly relying on lessons from other contexts.

In this study, a consumer survey was deployed in November 2016 to estimate how GTHA residents are likely to adopt, use, and respond to automated vehicles. This survey focuses on the vehicle ownership, travel behavior, and location decision elements of consumer choice to explore the relative impact of automated vehicles and their attributes on future travel behaviour. Adoption, use, and implications of automated vehicles will be differentiated between the two different ownership models. *Private automated vehicles* (PAVs) are owned by individuals and could be either semi-autonomous (still needing a driver sometimes) to fully-autonomous (no driver needed). *Shared autonomous vehicles* (SAVs), function very similarly to taxis or technology-enabled mobility products (e.g. Uber or Lyft) – except there is no driver. The potential role of policy will be discussed in the context of harnessing positive opportunities of AVs while limiting potential negative consequences.

2.0 Approach and Methodology

A survey was conducted in concert with Research Now in November, 2016 focusing on three core research questions:

- **Under what conditions can GTHA consumers be expected to adopt either private automated vehicles or shared autonomous vehicles?**

- **If private automated vehicles or shared autonomous vehicles are adopted, how are transportation system users likely to change their travel behaviour?**

- **What role could planning and policy play in managing automated vehicle adoption and use, to maximize benefits and minimize negative consequences?**

The data was obtained through an online survey of 3,201 adults in the Greater Toronto and Hamilton Area, ages 18 to 75. To reasonably represent the regional population, the survey was administered with hard targets for respondents within each of the two cities (Hamilton and Toronto) and four regional governments (Durham, Halton, Peel and York Regions). Additional information about the survey data collection and descriptive findings can be found in the Automated Vehicles in the report, *Greater Toronto-Hamilton Area: Overview from a 2016 Consumer Survey* (Olsen, Laidlaw, and Sweet, 2017). Targets were:

Durham Region - 400

Halton Region - 300

Hamilton - 300

Peel Region - 500

Toronto - 1200 (300 in each of the four operational districts)

York Region - 500

After data collection, results were adjusted based on the sample age groups, gender and region of residence to align with Statistics Canada estimates of the underlying population (Olsen, Laidlaw, & Sweet, 2017). The proportions of each of these groups was weighted to align with the observed proportions of the respective gender/age/region group based on Statistics Canada estimates. As the 2011 Statistics Canada data used as a reference only had female/male descriptors for gender, adjustments to this group reflect the mean gender-specific adjustments for each age group in each region.

In representing an underlying population in the GTHA of approximately 4.8 million 18 to 75-year olds, each individual in the survey represents, on average, 1,498 individuals, depending on the relative survey frequency of any given gender, region, and age group combination.

2.1 Forecasting Framework

The survey asked questions related to current demographic characteristics, household characteristics, attitudes and preferences, and current travel behaviours. The survey also asked preference questions to evaluate how respondents would adopt, use, or purchase automated vehicles in the future.

Probit models were estimated using survey data to estimate the effect of individual, household, land use, and attitudinal characteristics of survey participants on the willingness to pay for a fully self-driving car and price thresholds for frequency of using a fully self-driving shared vehicle.

Model results used to develop forecasts are presented in the Appendix and suggest three key findings (among others) for the purposes of forecasts:

1. AV information – those consumers who knew of the Google Car were more interested in AVs.
2. Demographics – those consumers who were youngest (<35) were most interested in AVs, while those over 55 were least interested.
3. Land use patterns – consumers living in neighborhoods with a higher job density within ten kilometers were significantly more interested in adopting or using an AV.

2.2 Scenario Components

Using the survey data, models were built to estimate future market shares for privately held automated vehicles and mode share for shared autonomous vehicles. The framework for forecasting the medium-term and long-term adoption of personal and shared automated vehicle technology consists of several stages. It is critical to highlight that each of these forecasts is subject to the preferences expressed in the November 2016 AV survey for the GTHA, so monitoring changes in these preferences over time will become important in estimating future demand as AV technologies evolve.

Several noteworthy assumptions are made for the purposes of generating forecasts:

1. It is assumed that a household replaces their vehicle at least every 10 years. This allows every consumer to have a chance to replace their vehicle with a fully automated vehicle.

2. It is assumed that only people who currently own a vehicle will potentially transition to a privately-owned fully automated vehicle; the model assumes that autonomous vehicles will not induce demand for additional vehicle ownership.

3.It is assumed that fully automated vehicles are available which closely mirror the current fleet composition (e.g. that they are available in similar sizes, body styles, and fuel efficiency) -

making the decision of AV ownership practically independent of the decision of body type, style, size, and fuel efficiency.

4. It is assumed that automated vehicle ownership does not diminish the intrinsic value of a vehicle - for example, image and/or performance-related amenities of vehicle ownership.

5. Upon having explored model results, it is assumed that private ownership of AVs would not preclude use of shared AVs and vice versa. Insofar that this assumption may not reflect behavioral motivations, these forecasts may overestimate shifts towards both private and shared use models of AVs.[1]

Several policy-relevant factors which can shape demand for driverless cars are used to develop future scenarios. While some of those factors can be shaped much more quickly (e.g. disseminating information to the public about this new technology), others are much slower to change (e.g. changes in land use due to development and growth). Those factors include:

<u>Information Provision Related to AVs</u>

The role of consumers becoming better informed about AVs in shaping ownership and use of driverless cars is explored. The effect of knowledge of AVs is modeled through a survey question indicating whether an individual has heard of the Google Car or not (a variable estimated to have a strong effect on AV ownership and use). It is likely that the private sector will invest heavily in advertising and consumers will learn more about the cars as they appear on roads. Moreover, the public sector may adopt campaigns to learn about AVs and disseminate information on the advantages and challenges associated with this new technology. As such, it is expected that consumers will become more informed regarding AVs over time and forecasts directly integrate this expectation.

[1] Based on willingness to use shared AVs, mode shares would be very low - suggesting that there are limited opportunities for these modes to compete for the same users.

Price of Technology

Using models, this study estimates how much of a premium consumers are willing to pay to purchase a private automated vehicle and how frequently they are willing to use a shared autonomous vehicle based on different price thresholds. Adoption rates are modeled through survey questions indicating how much a consumer would be willing to pay for a private automated vehicle (relative to a conventional vehicle) and how frequently consumers would use shared autonomous vehicles under different price thresholds (per kilometer). As the private sector advances innovation and technology, the price of automated vehicle technology is expected to decrease. Public policies may also contribute to either decreasing or increasing the price of technology for the consumer. In fact, among primary factors used to design scenarios (which also include *consumers' knowledge of AVs*, *demographics*, and *land use patterns*), prices are expected to be the most dynamic.

Private driverless car ownership models focus on two price premiums: $1,000 more than a conventional car and $15,000 more than a conventional car. These prices indicate scenarios under which price differences are very low or high. This approach is adopted due to uncertainty in response to intermediate premiums. Shared driverless car use scenarios are based on models which assume prices of $0.50, $1.00, and $1.50 per kilometer - already similar to the current average cost of operating and owning a car but significantly less than the average taxi or Uber trip.

Demographics

Models from this study as well as others (e.g. Hardman, Shiu & Steinberger-Wilckens, 2016) indicate that younger individuals are more likely to be early adopters of new technologies than older individuals. In fact, it is unclear whether these age-related effects are simply due to age, stage of lifecycle, and level of responsibility, or whether they are due to cohort effects which are likely to remain with specific generations over time as they age. As future consumers age, it is expected that some of their knowledge of and attitudes towards technologies such as AVs are likely to be retained over time.

For the purposes of future forecasts, it is expected that residents of the GTHA will increasingly retain attitudes which are more similar to the youngest current age cohorts (under 35). Given that predictive models indicate that younger users are more likely to use and adopt AVs, the relative equalization of age-specific preferences in models (such that in several decades, individuals over 55 adopt preferences more similar to those currently under 35) is used as a means to operationalize demographic adaptation and familiarization with AVs over time. Especially given the aging of the underlying population (currently the baby boom generation), it could likely be the case that individuals in older age cohorts comprise a larger share of the overall population – leading to structural shifts away from interest in AVs. As such, overall demographic shifts in preferences towards current younger generations (<35) represents an assumption of non-trivial changes in preferences among GTHA demographic groups.

Land Uses

The effect of increasing job density within ten kilometers of a given forward sortation area (FSA) is introduced in scenarios as a means of accounting for background growth. This metric captures the role of urban density and provides a means to operationalize changes in land use and growth over time. For the purposes of building the scenarios, a job growth rate of 1.6% a year is assumed. While this may be more aggressive than expected based on provincial forecasts (e.g. the Growth Plan for the GGH), it serves as an upper-bounds with respect to potential adoption of AVs. Predictive models (see the Appendix) indicate that higher concentrations of employment are associated with greater interest in autonomous vehicles.

Scenario Building

To explore the possible future ownership and use of autonomous vehicles, several scenarios are developed. Although these scenarios are described based on specific years (ten, thirty, and fifty-year futures), they should ultimately be interpreted on a continuum. The ten-year forecast represents a medium-term outcome which is long-enough for most current vehicle owners to have replaced their cars once. The fifty-year forecast represents a long-term future in which significant social, technological, information, and price changes are likely.

Scenarios are estimated using probit models to adjust the values of covariates based on scenario-specific assumptions to re-estimate predicted group membership (representing either the premium respondents are willing to pay for a PAV or the number of SAV trips taken per month) and aggregating predicted group membership on the basis of population weights. Central values are assumed as typical in the case of group membership in SAV models (e.g. 1-3 trips per month are assumed to typically be 2 trips per month).

Forecasted scenarios include:

1. **Base Case -** This acts as the effective base case where no changes to public preferences or policy actions are taken**.** The effective base case is estimated from the predictive models (see Appendix), which is slightly different than the observed descriptive statistics from the raw survey data. As such, takeaways from this report should focus not just on absolute estimates but on relative changes between different scenarios.
    - **a.** job density does not change
    - **b.** consumer knowledge remains as currently (50.3% of consumers know about the Google Car), and
    - **c.** no demographic change (age-specific preferences are expected to remain the same as currently estimated in inferential models).
2. **Ten-Year Future** – a medium term future in which most consumers will have replaced their vehicle once
    - **a.** job density grows (by 17%),
    - **b.** consumer knowledge increases (75% of consumers know about the Google Car), and
    - **c.** no demographic change (age-specific preferences are expected to remain the same as in the base case).

3. **Thirty-Year Future** – a longer-term future in which significant social change is possible
    a. job density grows (by 61%),
    b. consumer knowledge increases (85% of consumers know about the Google Car), and
    c. older demographic cohorts have more similar preferences to today's younger cohorts (cohort-specific effects are 50% as pronounced as currently).
4. **Fifty-Year Future** – a long-term future in which significant social change is expected
    a. job density grows (121%),
    b. consumer knowledge increases (95% of consumers know about the Google Car), and
    c. older demographic cohorts have even more similar preferences to today's younger cohorts (cohort-specific effects are only 25% as pronounced as currently).

Using each of these four scenarios, forecasts are developed to estimate shares of privately-owned autonomous vehicles (PAVs) and the share of trips taken using shared autonomous vehicles (SAVs). These are estimated as follows:

1. Additional willingness to pay for a fully automated PAV is estimated under two different pricing scenarios: $1,000, and $15,000 more than conventional vehicles which are otherwise equivalent.

2. Frequency of using a shared autonomous vehicle is estimated under three different pricing scenarios: $0.50/km, $1.00/km, and $1.50/km. For the purposes of generating mode shares, it is globally assumed that each individual takes 100 trips per month. As such, mode shares can likewise be multiplied by 100 to represent the forecasted number of SAV trips per person in a specific scenario.

3.0 Findings

The ownership and use of driverless cars based on private ownership and shared use models have enormous potential implications for transportation and urban planning. In this section, we present findings relating to consumer interest in adopting and using AVs. Implications for public policy are discussed in light of study findings in in *Section 4 (Public Policy Implications).* The first two th*emes are:*

- **Explore the conditions under which consumers will purchase private automated vehicle technology and use shared autonomous vehicles.**
- **Estimate future market shares of private automated vehicles and future mode share of shared autonomous vehicles under a set of alternative scenarios.**

This section will first provide a descriptive overview of the results from several questions in the Automated Vehicle 2016 Consumer Survey. Predictive models and forecasts will then be presented to discuss the outlook for consumer adoption and use of AVs.

3.1 Willingness to Pay for a Fully Automated Vehicle

Beyond questions relating to individual, household, neighborhood, and travel characteristics asked of survey participants, several questions on attitudes and willingness to pay for or use driverless car technology play important roles in forecasts. One such question, related to consumer willingness to pay for fully autonomous vehicles, provides the basis of driverless vehicle ownership forecasts. That question is:

If you are purchasing a new vehicle, how much more would you be willing to pay for it to be available as a fully driverless car as opposed to a conventional car?

Less than $1000

$1000-$4999

$5,000 to $9,999

$10,000 to $14,999

More than $15,000

Table 1: Willingness to Pay for a Level 5 Automated Vehicle (Weighted)

Willingness to Pay for Level 5 Automation						
I would not purchase an AV	< $1000	$1, 000 - $4, 999	$5,000 - $9,999	$10-$15k	> $15,000	Non Auto-Owners
25.2%	13.1%	22%	14.4%	7%	8%	10.4%

Responses suggest that the willingness to pay for self-driving cars is mixed. *Table 1* summarizes respondents' willingness to pay (WTP) for Level 5 automation relative to a conventional motor vehicle. One-quarter (25.2%) of respondents indicated that they have no interest in buying a driverless car, a proportion that is highest (42%) amongst drivers in the 55-75 age group. Only 8% of respondents would be willing to pay an additional $15,000 or more for a fully automated vehicle. The distribution of survey responses provides some indication that vehicle cost will be a strong determinant of private automated vehicle adoption rates in the GTHA. Roughly one-third (35.1%) of respondents are willing to pay a small premium (less than $5,000) for Level 5 automation.

3.2 Private Automated Vehicle Market Shares

Using AV premiums relative to conventional cars of $1,000 and $15,000, inferential model estimates (see the Appendix) are used to generate forecasts, as discussed in Section 2.0. There are a minority of users who have relatively inelastic demand for automated vehicles. These early adopters are willing to pay a substantial premium of $15,000 for a private automated vehicle, but they represent a small share of the total market. At a price premium of $1000, a much higher share of consumers are willing to shift to owning a private AV rather than a conventional vehicle. To estimate the upper and lower bounds of adoption, these two price premiums ($1,000 and $15,000 more than a conventional vehicle) are used for analyses and forecasts at intermediate prices are not estimated. As such, models are designed to explore ownership of AVs in response to higher ($15,000) premiums - which most closely approximates when the technology is first commercially available - and a very low price premium ($<1,000) - which might be expected when this technology is mature.

Rather than focusing immediately on the ten, thirty, and fifty-year forecasts, initial forecasts are generated in which only one factor is changed at a time (rather than several factors simultaneously in the longer-term forecasts). Forecasts are developed to compare the Base Case with changes exclusively to land use patterns (50% more dense), demographic upheaval (age-related differences in AV preferences are decreased by 50%), and the availability of consumer information is more widespread (all consumers are aware of the Google Car). While these scenarios are synthetic, they provide guidance on the relative strength of each of these factors in affecting interest in AVs.

Table 2: Private Automated Vehicle Market Shares Estimates

Future Scenarios	Market Share of AVs	
	$1,000	*$15,000*
Base Case*	46.2%	1.8%
Land Use (1.5x Employment Density)	48.7%	2.5%
Demographic Upheaval (0.5x Age Group Effect)	54.9%	2.1%
Consumer Information (100% Know about the Google Car)	56.6%	2.4%

** Note: the base case represents the effective market share, rather than the observed market share and therefore should be interpreted in relative, rather than absolute, terms.*

In *Table 2*, market share estimates are shown to illustrate the estimated individual effect each condition has on the additional willingness to pay for an automated vehicle. Each condition (land use, demographic upheaval, and consumer information) is discrete. Results suggest that:

- Price is a critical component to achieving sizable market shares. Until the difference between purchasing a conventional vehicle and an AV is less than $1,000 based on current preferences, the majority of consumers will not transition from a conventional vehicle to an automated vehicle.
- Increasing consumer knowledge of AVs is both feasible to implement and has a strong effect on increasing the market share of private automated vehicles. Based on survey results just over 51% of respondents have heard of the Google car. It is reasonable to assume that consumer knowledge will increase, and based on the forecast, widespread consumer knowledge of the Google car (100% of have heard of it) is expected to lead to a 57% market share at a $1,000 price premium and a 2.4% share at a $15,000 price premium.
- The effects of denser land use patterns on interest in AVs is most pronounced at higher prices (i.e. when the technology first becomes commercially available) rather than at lower price premiums (when the technology is more mature).

- The impacts of demographic upheaval (shifts in consumer preferences such that older cohorts' preferences mirror those of individuals currently under 35) can be strong but it is unclear how likely such shifts are.

3.3 Future Market Share Scenarios for Private Automated Vehicles

Table 3 introduces a set of alternative futures discussed in Section 2.1 and presents estimated market shares of private fully autonomous vehicles in response to demand under either $1,000 or $15,000 price premiums relative to conventional cars. Estimates were made for three different time periods (ten, thirty, and fifty years) to explore the influence of various factors that can reasonably be expected to change over time.

Table 3: Scenarios Estimating Private Automated Vehicle Market Shares

Future Scenarios		**Market Share of AVs**	
		$1,000	*$15,000*
Effective Base Case	No Change	**46.2%**	**1.8%**
Ten-Year Future	Land Use Density (1.17x) 75% Consumers know about the Google Car No Demographic Change	**51.1%** (+10.6%)*	**2.0%** (+11.1%)*
Thirty-Year Future	Land Use Density (1.61x) 85% Consumers know about the Google Car Decrease age effect by 50%	**64.9%** (+40.5%)*	**3.4%** (+88.9%)*
Fifty-Year Future	Land Use Density (2.21x) 95% Consumers know about the Google Car Decrease age effect by 75%	**77.7%** (+68.2%)*	**4.8%** (+166.7%)*

* Market Share % Increase (Difference from Base)

Results indicate that:

- Nearly half (with little additional change) to 80% (in the 50-year scenario) of the vehicle fleet could comprise of private automated vehicles if there is only a $1,000 price premium relative to conventional vehicles. The 50-year forecast assumes that land use density has increased by more than double, 95% of people know about automated vehicle technology, and that older respondents have become less averse to using a private automated vehicle.
- Over the long-term, market shares of private fully automated vehicles are likely to remain under 5% if a price premium of $15,000 persists.

3.4 Estimating Frequency of Using a Shared Autonomous Vehicles

Beyond questions relating to individual, household, neighborhood, and travel characteristics asked of survey participants, several questions on attitudes and willingness to pay for or use driverless car technology play important roles in forecasts. One such question, related to consumers' frequency of using fully self-driving cars at different price thresholds. This question provides the basis of shared driverless vehicle mode share forecasts. The following price points were selected because the average cost of owning and operating a personal vehicle is approximately $0.54 per km; testing consumer preferences at these three price points indicates whether the cost of an shared autonomous vehicle needs to be equivalent to a personal vehicle to enable consumer adoption. Another question was asked related to interest in using an SAV to access or egress public transit services, but the forecasts discussed here focus exclusively on trip taking for all purposes other than accessing/egressing public transit.

The question is:

If Uber-style shared driverless cars can pick you up and drive you anywhere in the Greater Toronto Area for a price of $0.50/1.00/1.50 per km, how often would you use this service for commuting or other trip purposes (not including accessing public transit)?

Never

Less than once per month

Between one and 3 times a month

At least once a week

Daily

Table 4: Frequency of Using a Shared Automated Vehicle (Weighted)

		SAV $0.50 per km		
Never	< 1 month	1-3 per month	At least once a week	Daily
31%	31%	24%	12%	3%
		SAV $1.00 per km		
Never	< 1 month	1-3 per month	At least once a week	Daily
56%	26%	12%	5%	1%
		SAV $1.50 per km		
Never	< 1 month	1-3 per month	At least once a week	Daily
70%	20%	7%	3%	1%

Table 4 presents survey results and illustrates significant price sensitivity, whereby over two-thirds (70%) of respondents were unwilling to use SAVs at a price of $1.50 per kilometer, whereas less than one-third (30%) were unwilling at a price of $0.50 per kilometer. Any individual who answered “never” at a particular price point was not asked the same question again at a higher price; these respondents were automatically coded as “never” for the subsequent SAV questions. Survey respondents were generally uninterested in regularly using a SAV service even at the lowest price point. Approximately 3% of respondents indicated that they would use an SAV every day at $0.50 km while 12% of respondents indicate that they would use a SAV at least once a week at $0.50 per km but that number drops to 5% at a price point of $1.00 per km. At a price of $1.50 per km, very few respondents were interested in using an SAV service at any frequency. The proportion of residents who would use an SAV service at least once a month is 24% and 7% at price points of $0.50 and $1.50 per km respectively; the marginal price of an SAV will largely dictate how many residents choose to use this service. Overall, results are consistent with respondents using SAV services to play similar roles as occasional use of taxi/Uber services – rather serving to replace significant shares of current travel behavior.

3.5 Future Mode Share Scenarios for Shared Autonomous Vehicles

Using the forecasting approach discussed in Section 2.0, future mode shares are estimated for SAV trips. As mode shares are estimated on the basis of the assumption that a typical individual engages in 100 trips per month, the mode shares (when multiplied by 100) are identical to estimates of SAV trips per person per month. As such, an estimated mode share of 0.68% would be equivalent to an average of 0.68 trips per person each month. As discussed in Section 2.0, SAV mode share forecasts assume that SAV travel does not compete with use of privately-owned AVs. Insofar that this assumption is not correct, these forecasts are expected to represent overestimates of AV mode shares.

Table 5: Scenarios Estimating Shared Autonomous Vehicle Mode Shares

Future Scenarios		**Mode Shares of On-Demand SAVs**		
		$0.50 / km	*$1.00 / km*	*$1.50 / km*
Effective Base Case*	No Change	**0.63%**	**0.17%**	**0.041%**
10 year future	Land Use Density (1.17x) 75% Consumers know about the Google Car No Demographic Change	**0.68%** (+7.9%)*	**0.18%** (+5.6%)*	**0.045%** (+9.8%)*
30 year future	Land Use Density (1.61x) 85% Consumers know about the Google Car Decrease age effect by 50%	**0.74%** (+17.5%)*	**0.20%** (+17.6%)*	**0.057%** (+39.0%)*
50 year future	Land Use Density (2.21x) 95% Consumers know about the Google Car Decrease age effect by 75%	**0.79%** (+25.4%)*	**0.22%** (+29.4%)*	**0.085%** (+107.3%)*

* % Mode Share Increase (Different from Base). * Note, the base case represents the effective market share, rather than the observed market share and therefore should be interpreted in relative, rather than absolute, terms.

Forecasts suggest several major findings regarding future SAV use.

- Without significant social and preference changes in GTHA residents, the percentage of trips taken by shared autonomous vehicles is expected to remain low, even in the long term. We estimate that just under 1% of trips, or 1 in 100 trips in the GTHA will be taken using a shared autonomous vehicle if the service is available at a price of $0.50/km. This is similar to the current cost of operating a conventional vehicle today. In order to see a significant shift towards shared autonomous vehicles, the price of automation may have to decrease substantially relative to the current price of operating a car (perhaps through other changes to the vehicle typologies). Findings are inconsistent with the view that automated vehicles represent an opportunity to dramatically decrease personal vehicle use and suggest they act as a complement option to residents, offering another mode of travel.

- When extracting both mode shares and the shares of residents (aged 18 to 75) expected to use SAVs, results suggest that approximately 57% of individuals would use SAVs (even if infrequently) according to the Base Case at a price of $0.50 per kilometer. These user shares would be expected to increase to 63% (10-year forecast), 70% (30-year forecast), and 77% (50-year forecast). This suggests that even though mode shares of SAVs are expected to remain low, a large share of GTHA residents are expected to become occasional SAV users.

4.0 Public Policy Implications

Automated vehicles (AVs) appear to be poised to change how goods and people travel and move in cities. To leverage AVs as tools to meet rather than compromise broader social and policy goals, policymakers and transportations planners in the GTHA will need to understand both the nature of new AV technology and plausible travel behavior impacts.

The findings of this study provide insight into how GTHA consumers will adopt and use both private automated vehicles and shared autonomous vehicles. Results from this study provide early evidence on how we can expect the future of automated vehicles to unfold in the GTHA and influence private vehicle fleets and SAV mode shares, allowing policymakers to consider implications for broader policy objectives. While the diffusion and adoption is currently being nurtured and advanced by the private sector, the public sector has a potentially significant role to play in understanding and managing the future of automated vehicle technology.

For policymakers and transportation planners to be best positioned to plan for AVs (regardless of ownership model) towards considering broader policy goals, results from this study support several key considerations.

- First, transportation planners should learn about and disseminate information regarding automated vehicles and implications in cities. Given the wide range of implications of AVs, knowledge gathering and distribution should include multiple stakeholders, including the private sector, various public entities involved in the transportation system, and the public at large. In fact, knowledge of AVs is a strong predictor of consumer interest in adopting and using AVs, highlighting the importance of transparency and good information.

- Second, results indicate significant potential interest in adopting privately-owned AVs. Descriptive results using raw data suggest eight percent of current vehicle owners would be willing to pay a $15,000 premium over conventional vehicles to buy an AV, while forecasts suggest approximately two percent uptake without any broader social changes. For the share of PAVs to exceed fifty percent (and even reach as high as three-quarters), the price premium would need to be no more than $1,000 more than conventional vehicles. Given that current auto mode shares in the GTHA are approximately 80%, a fifty percent PAV share in the vehicle fleet would represent an approximately 40% PAV mode share. These potential changes in the transportation system are of consequence. To maximize the social and environmental benefits from this shift, planners should document, monitor, and proactively manage the balance of advantages and disadvantages from more PAVs on urban streets.

- Third, without significant changes in consumer preferences, on-demand shared autonomous vehicles do not appear poised to represent a significant mode share (less than one percent). Rather SAVs do appear to be poised to be used on rare occasions by many GTHA residents – between half and three-quarters of GTHA residents at a price of $0.50 per kilometer. Monitoring and understanding the potential factors affecting the prices of on-demand, shared autonomous vehicle is important should SAVs be viewed as one means of accomplishing broader public policy objectives. Depending on policy objectives, the difference between the price to operate and to consume such a service may lead to the consideration of a public subsidy, public regulation, or the public sector to play a role as a service provider - perhaps even in a public-private partnership model. Price appears to matter significantly to prospective consumers. Model results suggested that a price of at most $0.50 per kilometer would be needed to achieve a 0.79% mode share whereas even at $1.00 per kilometer, the mode share would be expected to be one-third as high.

- Finally, forecasts indicate that based on current preferences and plausible future changes, there will be a mixed driverless car and conventional car vehicle fleet mix in the Greater Toronto-Hamilton Area. The likelihood of such a mix suggest the need for regional multimodal planning to explore broader implications. This mix is expected include significant numbers of privately-owned AVs which will outnumber the use of on-demand shared AVs by a factor of five to ten. Admittedly, it is conceivable that PAVs are the very vehicles rented out in the on-demand shared market, but even this remains to be seen. Forecasts suggest that a mixed vehicle fleet (of PAVS, SAVs, and conventional vehicles) is likely in the future. Insofar that accelerating the transition towards completely autonomous vehicles is desirable (perhaps due to platooning, traffic flow, and safety improvements), the results from this study suggest that there will be a public policy role for regulation of vehicles even beyond the price, consumer information, land use changes, and demographic shifts explored in study scenarios. Given that vehicles operating in Ontario are shaped by both provincial regulations and those of other jurisdictions (e.g. the Canadian government or US federal requirements), Ontario's regulatory context must be shaped either in concert or with respect to those other jurisdictions as well.

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Appendix: Results

Table 6: Probit Model - Additional Willingness to Pay for a Fully Automated Vehicle[2]

Reference groups: Age (18-34), HH Income (0-$14,999), Female, Do not own a smartphone, and Aware of Google Car)

Explanatory Variables:	**Value**	**Std Error**	**T Value**
Age (35-54)	-0.086037	0.05039	-1.7073
Age (55-75)	-0.340499	0.06156	-5.5309
HH Income ($15,000 to $39,999)	0.384375	0.18937	2.0298
HH Income ($40,000 to $59,999)	0.389291	0.18352	2.1213
HH Income ($60,000 to $99,999)	0.500575	0.17964	2.7866
HH Income ($100,000 to $124,999)	0.414136	0.18473	2.2419
HH Income ($125,000 to $175,000)	0.497299	0.18517	2.6856
HH Income ($175,000 and above)	0.597292	0.18745	3.1864
HH Income (Prefer not to answer)	0.353393	0.18443	1.9161
HH Income (I don't know)	-0.066503	0.2172	-0.3062
Gender (Male)	0.055675	0.04099	1.3582
Gender (other)	-0.144692	0.31678	-0.4568
Own a Smart Phone	0.185602	0.06839	2.7138
Physically Disabled	0.032893	0.04085	0.8052
# of Driver Collisions	-0.04445	0.03577	-1.2427
# of Passenger Collisions	0.047869	0.04154	1.1524
Household Size	0.006166	0.01577	0.391
Job Density (10 k radius)	0.083009	0.02943	2.8206
Uber (have previously used)	0.226046	0.06415	3.5238
Uber(1-3 per month)	0.410638	0.07485	5.4859
Uber (1 per week)	0.43235	0.11853	3.6475
Uber (2+ per week)	0.232555	0.14046	1.6556
Travelled Yesterday	0.136416	0.06354	2.1469
Not aware of the Google Car	-0.195788	0.04198	-4.6642
Intercepts:	**Value**	**Std Error**	**T Value**
1|2	0.1363	0.2017	0.6756
2|3	0.557	0.2019	2.7593
3|4	1.2244	0.2025	6.0447
4|5	1.772	0.2034	8.7111
5|6	2.1606	0.2044	10.5703

Residual Deviance: 9413.28 AIC: 9471.28

[2] *If you are purchasing a new vehicle, how much more would you be willing to pay for it to be available as a fully driverless car as opposed to a conventional car?*
Less than $1000
$1000-$4999
$5,000 to $9,999
$10,000 to $14,999
More than $15,000

Table 7: Probit Model - Frequency of Using a Shared Autonomous Vehicle at $0.50 / km[3]

Reference groups: Age (18-34), HH Income (0-$14,999), Female, Do not own a smartphone, and Aware of Google Car)

Explanatory Variables:	**Value**	**Std Error**	**T Value**
Age (35-54)	-0.03934	0.04807	-0.8183
Age (55-75)	-0.05092	0.05888	-0.8648
HH Income ($15,000 to $39,999)	-0.1332	0.14215	-0.937
HH Income ($40,000 to $59,999)	0.02654	0.13905	0.1909
HH Income ($60,000 to $99,999)	0.05463	0.13601	0.4017
HH Income ($100,000 to $124,999)	-0.04645	0.14311	-0.3246
HH Income ($125,000 to $175,000)	0.04991	0.14367	0.3474
HH Income ($175,000 and above)	-0.03224	0.14667	-0.2198
HH Income (Prefer not to answer)	-0.15684	0.14112	-1.1114
HH Income (I don't know)	-0.30583	0.17477	-1.7499
Gender (Male)	0.03328	0.03942	0.8442
Gender (other)	0.3742	0.25896	1.445
Own a Smart Phone	0.3827	0.06382	5.9964
Physically Disabled	0.07782	0.03859	2.0169
# of Driver Collisions	-0.05593	0.03481	-1.6069
# of Passenger Collisions	0.12987	0.03934	3.301
Household Size	0.04498	0.01495	3.0092
Job Density (10 k radius)	0.09704	0.02821	3.4402
Uber (have previously used)	0.63608	0.06196	10.2659
Uber(1-3 per month)	0.7113	0.07146	9.9532
Uber (1 per week)	0.64125	0.11115	5.7695
Uber (2+ per week)	0.83005	0.12991	6.3892
Travelled Yesterday	-0.06744	0.05104	-1.3213
Not aware of the Google Car	-0.17088	0.04001	-4.2707
Intercepts:	**Value**	**Std Error**	**T Value**
1|2	0.0741	0.1564	0.474
2|3	0.9493	0.1569	6.0486
3|4	1.7869	0.1586	11.2645
4|5	2.6825	0.1636	16.4001

Residual Deviance: 8602.511 AIC: 8658.511

[3] *If Uber-style shared driverless cars can pick you up and drive you anywhere in the Greater Toronto Area for a price of $0.50 per km, how often would you use this service for commuting or other trip purposes (not including accessing public transit)?*
Never
Less than once per month
Between one and 3 times a month
At least once a week
Daily

Table 8: Probit Model - Frequency of Using a Shared Autonomous Vehicle at $1.00 / km[4]

Reference groups: Age (18-34), HH Income (0-$14,999), Female, Do not own a smartphone, and Aware of Google Car)

Explanatory Variables:	Value	Std Error	T Value
Age (35-54)	-0.09485	0.0501	-1.893
Age (55-75)	-0.22216	0.06229	-3.5664
HH Income ($15,000 to $39,999)	-0.27851	0.14642	-1.9021
HH Income ($40,000 to $59,999)	-0.20499	0.14315	-1.432
HH Income ($60,000 to $99,999)	-0.16496	0.13976	-1.1803
HH Income ($100,000 to $124,999)	-0.25208	0.14755	-1.7085
HH Income ($125,000 to $175,000)	-0.19766	0.14802	-1.3354
HH Income ($175,000 and above)	-0.29982	0.15139	-1.9805
HH Income (Prefer not to answer)	-0.40642	0.1458	-2.7875
HH Income (I don't know)	-0.4235	0.18102	-2.3395
Gender (Male)	-0.0172	0.04151	-0.4143
Gender (other)	0.46447	0.26146	1.7764
Own a Smart Phone	0.23106	0.06842	3.3769
Physically Disabled	0.10934	0.04048	2.7007
# of Driver Collisions	-0.05933	0.0367	-1.6165
# of Passenger Collisions	0.08802	0.04122	2.1352
Household Size	0.03763	0.01563	2.407
Job Density (10 k radius)	0.09971	0.02971	3.356
Uber (have previously used)	0.58018	0.06375	9.1013
Uber(1-3 per month)	0.70095	0.07296	9.6075
Uber (1 per week)	0.97895	0.1124	8.7095
Uber (2+ per week)	1.24473	0.1317	9.4513
Travelled Yesterday	-0.03481	0.05338	-0.6521
Not aware of the Google Car	-0.13155	0.04217	-3.1193
Intercepts:	**Value**	**Std Error**	**T Value**
1|2	0.1383	0.1621	0.8531
2|3	1.116	0.1631	6.8434
3|4	1.9322	0.1657	11.6643
4|5	2.7459	0.1759	15.6146

Residual Deviance: 7161.009 AIC: 7217.009

[4] *If Uber-style shared driverless cars can pick you up and drive you anywhere in the Greater Toronto Area for a price of 1.00 per km, how often would you use this service for commuting or other trip purposes (not including accessing public transit)?*
Never
Less than once per month
Between one and 3 times a month
At least once a week
Daily

***Table 9: Probit Model - Frequency of Using for Shared Autonomous Vehicle at $1.50 / km*[5]**

Reference groups: Age (18-34), HH Income (0-$14,999), Female, Do not own a smartphone, and Aware of Google Car

Explanatory Variables:	Value	Std Error	T Value
Age (35-54)	-0.136696	0.05367	-2.5468
Age (55-75)	-0.21223	0.06747	-3.1455
HH Income ($15,000 to $39,999)	-0.192642	0.15724	-1.2252
HH Income ($40,000 to $59,999)	-0.13149	0.15364	-0.8558
HH Income ($60,000 to $99,999)	-0.127049	0.15017	-0.846
HH Income ($100,000 to $124,999)	-0.155797	0.15861	-0.9822
HH Income ($125,000 to $175,000)	-0.151555	0.1593	-0.9514
HH Income ($175,000 and above)	-0.230985	0.16291	-1.4179
HH Income (Prefer not to answer)	-0.400027	0.15766	-2.5373
HH Income (I don't know)	-0.336467	0.19499	-1.7256
Gender (Male)	0.001532	0.04492	0.0341
Gender (other)	0.349746	0.27645	1.2652
Own a Smart Phone	0.165619	0.07561	2.1905
Physically Disabled	0.17204	0.04325	3.9779
# of Driver Collisions	-0.110728	0.04003	-2.7658
# of Passenger Collisions	0.077631	0.04431	1.7518
Household Size	0.046961	0.01677	2.8003
Job Density (10 k radius)	0.124923	0.03209	3.8932
Uber (have previously used)	0.415485	0.06805	6.1056
Uber(1-3 per month)	0.635394	0.07604	8.3565
Uber (1 per week)	1.138291	0.11422	9.9659
Uber (2+ per week)	1.297813	0.13389	9.693
Travelled Yesterday	-0.007912	0.05764	-0.1373
Not aware of the Google Car	-0.103322	0.04573	-2.2595
Intercepts:	**Value**	**Std Error**	**T Value**
1|2	0.6431	0.1745	3.6853
2|3	1.5925	0.1762	9.039
3|4	2.2851	0.1801	12.69
4|5	2.9563	0.1918	15.4145

Residual Deviance: 5768.374   AIC: 5824.374

[5] *If Uber-style shared driverless cars can pick you up and drive you anywhere in the Greater Toronto Area for a price of 1.50 per km, how often would you use this service for commuting or other trip purposes (not including accessing public transit)?*
Never
Less than once per month
Between one and 3 times a month
At least once a week
Daily