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Americans' Plans for Acquiring and Using Electric, Shared, and Self-Driving Vehicles and Costs and Benefits of Electrifying and Automating U.S. Bus Fleets

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Americans' Plans for Acquiring and Using Electric, Shared, and Self-Driving Vehicles and Costs and Benefits of Electrifying and Automating U.S. Bus Fleets

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2017

Acknowledgements

This work would not have been possible without the support of many in the academic community, all of whom deserve generous appreciation. The National Science Foundation's Sustainable Healthy Cities Research Network provided necessary financial support, and the many participants in the network provided helpful guidance on numerous occasions. Murthy Krishna Gurumurthy has been very generous with his time anytime I ran into issues that needed a second set of eyes, or needed guidance on coding. Pragun Vinayak always made himself available to listen to any challenges that came up in my work, and offer guidance on where I might find the resources to move forward. Prateek Bansal generously provided guidance based on his prior experiences on numerous occasions. The assistance and administrative support provided by Scott Schauer-West and Amy Banker has been instrumental in keeping me on schedule. My advisor, Dr. Kara Kockelman, continuously pushed me to achieve more and aim for a higher standard. The support provided by each of these people has been invaluable, and I extend my sincere gratitude to each of them.

I would also like to extend my appreciation to the faculty of the Transportation Engineering program at the Cockrell School, especially my second reader, Dr. Randy Machemehl, Dr. Steve Boyles, and Dr. C. Michael Walton, who, in addition to Dr. Kockelman, provided me with skills and insights through their classes which have proven invaluable. I would also like to thank Dr. Gian Claudia Sciara for her insights into transportation planning and Dr. Jay Zarnikau for the statistical analysis tools he taught me and the continued support he provided beyond the class content.

Finally, I must extend my appreciation to my friends and family, especially my parents, for their continued support and patience as I pursue this degree. I am also grateful for the assistance provided by my friends and family who tested and provided feedback on the initial drafts of the survey questionnaire used for Parts 1 and 2 of this thesis. My achievements have been dependant on all of these people, and I offer my deepest thanks.

Preface

This thesis is divided into three loosely-connected parts, all of which focus on future adoption of electric, autonomous, and shared vehicle technologies.

The first two parts are based on the results of a stated preference survey (which obtained travel behavior intentions, opinions, and other information from 1,426 Americans in early 2017). Thanks to the NSF Sustainable Healthy Cities research network for supporting this work. The first part reports and discusses summary statistics from the survey concerning attitudes towards electric, autonomous, and shared vehicle technologies, willingness to pay for, and intended travel behavior upon the availability of such technologies. This part also reports on policy opinions surrounding autonomous and shared vehicles, as well as intended shifts in home location choices upon the availability of the technologies. A paper based on this research was presented at the 2017 Automated Vehicles Symposium in July 2017, with Kara Kockelman as co-author.

The second part develops a simulation-based framework to predict Americans' long term (2017 to 2050) adoption of electric, autonomous, and shared vehicle technologies, and the makeup of the United States vehicle fleet and the resulting VMT, as well as home locations. Multiple scenarios are tested to gauge how changes in technology price premium and WTP, based upon vehicle characteristics, affect the decisions simulated. A publishable manuscript of this part is under preparation, with Kara Kockelman as co-author.

The third part analyzes the costs and effects of introducing electric and autonomous technology to transit bus fleets, using a case study of Capital Metro's fleet in Austin, Texas. Qualitative effects are discussed, financial effects are analyzed, and potential adoption schedules are developed. A paper based on this research has been accepted for presentation at the Transportation Research Board's 97th annual meeting in January 2018, with Kara Kockelman as co-author.

Abstract

Americans' Plans for Acquiring and Using Electric, Shared, and Self-Driving Vehicles and Costs and Benefits of Electrifying and Automating U.S. Bus Fleets

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This thesis is divided into three parts. The first part surveys 1,426 Americans to gauge how technology availability and costs influence public opinion, vehicle ownership decisions, travel, and location choices, and then adjusted all results for population weights, to offset any sample biases in U.S. demographics. Example results include average willing to pay (WTP) for full automation (on a newly acquired vehicle) of $3,252 with a very high standard deviation of +/- $3,861 with a human-driven-vehicle (HV) mode option and $2,783 (standard deviation = $3,722) without that option (AV driving only). These averages rise to $3685 and $3112 for AV with and without an HV option, respectively, if responses of zero WTP are removed. Americans' average WTP for use of shared autonomous vehicles (SAVs) is $0.44 per mile (standard deviation = $0.43). If given the option, Americans expect to set their vehicles in AV (self-driving) mode 36.4% of the time. Respondents believe about 20% of AV miles should be allowed to travel empty, for both privately-owned AVs and shared AV fleets, which would be quite congesting in urban regions at many times of day. Among those likely to move their home in the next few years, 15.5% indicate that availability of AVs and SAVs would shift their new home locations relatively closer to the city center, while 10% indicate further away; the other 74.5% do not expect such technologies to influence their home location choices.

The second part develops a simulation-based framework to predict fleet evolution and VMT through year 2050, based upon regression models calibrated with the results of the survey the previous part of this thesis. Multiple scenarios are tested to analyze the effect of the difference in willingness to for AVs when the option to retain human driving capabilities in AVs is available vs. when it is not, as well as the effect of different rates of decline in the AV technology price premium. Both are shown to have a substantial effect on AV adoption rates. Home location is also analyzed, and a slight migration away from city centers is observed.

The third part uses Capital Metro's transit bus fleet in Austin, Texas to analyze the costs and effects of implementing electric and autonomous technologies in transit bus fleets. Qualitative effects are discussed, financial effects are analyzed, and potential adoption schedules are developed. It is found that electric buses will become competitive with diesel in a few years, or immediately with a modest rise in diesel fuel prices within the range of historical levels. Autonomous buses will offer significant costs savings upon availability, and their implementation could ease the near-term cost burden associated with electric bus adoption in the near term before a substantial drop in electric technology price or rise in diesel fuel prices.

Table of Contents

List of Tables

List of Figures

PART 1: AMERICANS' PLANS FOR ACQUIRING AND USING ELECTRIC, SHARED AND SELF-DRIVING VEHICLES

Chapter 1: Introduction and Background to Part One

Autonomous, electric, and shared vehicle technologies are expected to experience rapid growth. Electric vehicles (EVs) have existed longer than their gasoline-fueled counterparts (since the late 1800s), and continuing battery-cost reductions are increasing their attractiveness. Shared vehicles are a more recent option, in the form of very-short-term rentals in urban areas. Cell phones, and their GPS, have made ride-hailing a key mode in many settings. Fully self-driving vehicles will impact all these options, and many more (Fagnant and Kockelman 2016).

EVs can reduce emissions and human health impacts in many power-source settings. Nichols et al. (2015) compared EV emissions vs. conventional light-duty vehicles in Texas. They estimated EVs to lower emissions of every analyzed pollutant except SO_2, thanks to coal as a power-plant feedstock. A shift away from coal, toward cleaner generation, would result in EVs lowering emissions of all pollutants. Reiter and Kockelman (2017) find emissions externalities of a typical EV to be about half that of a gasoline vehicle in Texas cities. For air quality, climate change, and energy-security purposes, many countries and states have initiatives to accelerate EV adoption, and revenues from EV charging may reduce electricity rate increases while saving EV owners money via overnight charging (Tonachel 2017). Interestingly, over 400,000 had put down $1,000 deposits for a Tesla Model 3 by the end of 2016 (Tonachel 2017).

Fagnant and Kockelman (2015) estimated (and monetized) many of AVs' benefits to society and their owners, improved safety, reduced congestion, and decreased parking needs, while noting issues of increased vehicle-miles traveled (VMT), by making travel easier, and more accessible (to those without drivers' licenses, for example). Dynamic ride-sharing (DRS) among strangers using SAVs can offset some of these issues, while improving response times and lowering SAV access costs in many contexts (e.g., at peak times of day, when an SAV fleet is heavily utilized). Litman (2015) anticipates some increased mobility shortly after introduction AV technologies, but most benefits, including improved traffic operations, safety, widespread mobility, and environmental improvements will likely take decades to become noticeable.

This research tackles topics and gaps left in past surveys regarding the technologies addressed here. Bansal and Kockelman (2017a) surveyed 2,167 Americans to calibrate a microsimulation model of U.S. light-duty vehicle fleet evolution, reflecting different technology price reductions and increases in households' WTP. Their 30-year simulation ended in 2045, but did not include electric or shared vehicles in any detail, and suggested an average WTP of $5,857 for full automation. Bansal and Kockelman (2017b) then surveyed 1,088 Texans, to understand WTP for, and opinions toward connected and autonomous vehicles (CAVs). This study did not address electric or shared technologies, or acquire a nationwide sample. Notably, 81.5% of those respondents (population-weight corrected) did not plan to shift home locations due to CAVs becoming available. However, those who are not already considering moving may be rather content with their home's location, and less able to thoughtfully consider moving in a hypothetical situation. Posing this question only to those considering moving, as done in this current study, may better reveal the technologies' effects.

Similarly, Schoettle and Sivak (2014) surveyed 1,533 adults in the U.S., United Kingdom, and Australia, to gauge public opinion about AV technology. Those with greater familiarity with AV technology had a more positive opinion and higher expectations of this technology. Overall, respondents expressed significant concern about AVs, especially AVs' driving abilities, security issues, empty vehicles. Females showed greater concern, as did Americans, on average. Respondents expressed desire to adopt the technology, but most indicated zero WTP, consistent with Bansal and Kockelman's (2017a, 2017b) results.

Studies addressing similar topics include Bansal et al. (2016), who estimated Austin, Texans' average WTP to be $7,253 to own an AV. They estimated how WTP for AVs and SAVs depends on various explanatory factors, and they used SAV pricing scenarios of $1, $2, and $3 per mile to gauge use estimates. Zmud et al. (2016) surveyed Austinites to better understand technology acceptance and use. They found a strong desire to own personal AVs, rather than share SAVs, and predicted AVs to increase regional VMT.

Javid and Nejat (2017) used the U.S. National Household Travel Survey to estimate adoption of plug-in electric vehicles (PEVs). And Musti and Kockelman (2011) and Paul et al. (2011) surveyed those residing in Austin, Texas, and then across the U.S. about EV purchase interests, in order to microsimulate the region's and, then, nation's fleet evolution over 25 years. Vehicle choice in the questionnaire was largely a series of choices between specific vehicle makes and models. They simulated effects of different gas and energy prices, demographics (like an aging population), and feebate programs, to incentivize purchase of hybrid and plug-in EVs. Paul et al. (2011) also simulated greenhouse gas (GHG) emissions over the 25-year period, demonstrating how higher gasoline prices provided the greatest GHG and VMT reductions. Higher population-density assumptions (for Americans' home locations, for example) also significantly reduced GHG and VMT forecasts, while lower PHEV pricing achieved little.

All previous studies lack a nationwide survey that is inclusive of electric, autonomous, and shared vehicle technologies. This study conducts such a survey, and investigates the effects of these technologies on travel behavior and home location choices.

Chapter 2: Survey Data

This study surveyed adult Americans (age 18 and over) regarding their and their households' willingness to acquire and/or use electric, autonomous, and shared vehicle technologies. A data-cleaning process removed respondents who sped through the questionnaire, or whose responses indicated a lack of attention or understanding of the questions (shown by nonsensical or excessively contradictory responses), resulting in a final sample of 1,426 respondents. These Americans come from all over the U.S., thanks to a panel of over 100,000 potential respondents maintained by Survey Sampling International (SSI), with the sample's spatial distribution largely mimicking population concentrations across the nation.

2.1 Sample Weighting

No random sample will exactly match the population intended, so a weighting process was performed to closely mimic U.S. demographics, providing weights for both individual respondents and the households they represent. Weighting was performed on the survey response data using a multidimensional iterative fitting process. PUMS data was obtained for multiple demographic variables and for combinations of variables, which was used at each step of the weighting process. Variables included gender, age, education level, marital status, race, household income, household size, household workers, and household vehicles. Each combination of variables, or individual variables when necessary, comprises a "dimension", and these dimensions were used as many times as necessary, via an iterative process, until they delivered a strong fit (as described below) between the sample and the U.S. population. The process was performed twice: once with all variables included, for application to questions addressing individual behavior or opinions (like willingness to pay for an SAV), and once with only household variables included, for application to questions addressing household decisions (like residential location moves).

For each iteration, i, weights were applied to make the sample demographics match the population demographics each dimension, using Equation (1) to determine the weight for each demographic category, where X_i is the number in category j in the U.S. population, N is the size of the U.S. population, n is the sample size, and x_i is the weighted number of respondents in category j entering the iteration. The weight produced for each category is multiplied by the previous weight for every respondent in the category, producing the master weight that is carried into the next iteration, which makes the sample demographics match the population demographics for the dimension in use. This multiplication slightly adjusts all other dimensions, necessitating multiple iterations to gradually correct them. These iterations are performed, rotating the dimension being used each time, until a full rotation of all dimensions is performed where no category of any dimension varies by more than 1% between the weighted sample and the population data. For example, if a category comprises 10.0% percent of the population, acceptable values would be between 9.9% and 10.1%. The appropriate weights are applied to all summary statistics presented in this report.

$$Weight_{j,i} = \frac{X_j}{N} * \frac{n}{x_j} * Weight_{j,i-1} \qquad (1)$$

The sample data (summary statistics for demographics are shown in Table 3.4 in the following chapter) contained too few men (37% vs. 49% in the U.S.), younger people (27% vs. 31% for those under age 35, for example), and those with lower income and education levels. Weights were computed using the U.S. Census Public Use Microdata Sample (PUMS) for combinations of gender, age, education, marital status, race, household income, household size, household workers, and household vehicles. The sampling correction values were computed via an iterative process, across PUMS-provided combinations until the weighted samples (first at the individual level, then at the household level) matched the population. The weights are applied to the sample to generate summary statistics representative of the U.S. population, and in Part 2, to also make the simulation results match the U.S. population. This work could be improved upon by also using the weights in the regression models presented in later chapters and in Part 2.

Chapter 3: Summary Statistics

As shown in Table 3.1, driving alone dominates all trip-purpose categories, excepting social/recreational trips, which are largely driven with others in the vehicle. SAV rides may be rather attractive for such multi-person trips, since the cost may be shared among a group.

Table 3.1: Summary Statistics (n = 1426 Americans, population corrected)

<table>
<tr><th colspan="7">Respondents' Primary Travel Mode by Trip Type</th></tr>
<tr><th>Trip Purpose</th><th>Walk</th><th>Bicycle</th><th>Drive Alone</th><th>Drive w/ Others</th><th>Public Transport</th><th>Not Applicable</th></tr>
<tr><td>Work</td><td>3.1%</td><td>0.7%</td><td>52.0%</td><td>6.3%</td><td>3.5%</td><td>34.3%</td></tr>
<tr><td>School</td><td>1.9%</td><td>1.1%</td><td>21.5%</td><td>7.6%</td><td>2.9%</td><td>65.1%</td></tr>
<tr><td>Shopping</td><td>1.8%</td><td>0.4%</td><td>59.1%</td><td>32.9%</td><td>4.3%</td><td>1.5%</td></tr>
<tr><td>Personal Business</td><td>0.3%</td><td>0.9%</td><td>59.3%</td><td>10.4%</td><td>4.0%</td><td>25.2%</td></tr>
<tr><td>Social/Recreational</td><td>1.8%</td><td>0.6%</td><td>33.4%</td><td>53.8%</td><td>4.0%</td><td>6.3%</td></tr>
<tr><td>Other</td><td>0.5%</td><td>1.0%</td><td>57.6%</td><td>20.0%</td><td>3.6%</td><td>17.3%</td></tr>
<tr><th colspan="7">How Expect Household to Acquire Its Next Vehicle (by % Respondents)</th></tr>
<tr><td></td><td colspan="3">New</td><td colspan="3">Used</td></tr>
<tr><td>Purchase</td><td colspan="3">54.3%</td><td colspan="3">37.6%</td></tr>
<tr><td>Lease</td><td colspan="3">6.2%</td><td colspan="3">1.8%</td></tr>
<tr><th colspan="7">Type of Vehicle for Next Acquisition Among Those Intending to Purchase a Vehicle in the Future</th></tr>
<tr><td colspan="4"></td><td colspan="3">% Respondents</td></tr>
<tr><td colspan="4">Gasoline or diesel-powered sedan</td><td colspan="3">35.9%</td></tr>
<tr><td colspan="4">Gasoline or diesel-powered coupe or compact car</td><td colspan="3">9.9%</td></tr>
<tr><td colspan="4">Gasoline or diesel-powered minivan, SUV, or CUV</td><td colspan="3">28.3%</td></tr>
<tr><td colspan="4">Gasoline or diesel-powered pickup truck</td><td colspan="3">8.4%</td></tr>
<tr><td colspan="4">Hybrid-electric vehicle</td><td colspan="3">13.0%</td></tr>
<tr><td colspan="4">Plug-in hybrid-electric vehicle</td><td colspan="3">2.1%</td></tr>
<tr><td colspan="4">Fully electric vehicle</td><td colspan="3">2.5%</td></tr>
<tr><th colspan="7">Interest in Owning or Leasing an AV, Assuming the Price is Affordable</th></tr>
<tr><td>Very Interested</td><td colspan="2">Moderately Interested</td><td colspan="2">Slightly Interested</td><td colspan="2">Not Interested</td></tr>
<tr><td>21.3%</td><td colspan="2">19.0%</td><td colspan="2">23.5%</td><td colspan="2">36.2%</td></tr>
<tr><th colspan="7">Preference of Vehicle Type, Disregarding Price Premium</th></tr>
<tr><td colspan="2">Self-Driving</td><td colspan="3">Human-Driven</td><td colspan="2">No Vehicle Purchase</td></tr>
<tr><td colspan="2">32.4%</td><td colspan="3">61.8%</td><td colspan="2">5.8%</td></tr>
</table>

Table 3.1, cont.

Logit Coefficients for AV-related Choices						
	Prefer AV over HV, ignoring price premium ($n =$ 1426, $Pseudo\ R^2$ $= 0.077$)		% travel distance in AV mode if household vehicle is capable of both ($n = 1426$, $Pseudo\ R^2 = 0.033$)		% of SAV rides with stranger, if DRS costs $0.60 instead of $1/mi. ($n = 1426$, $Pseudo\ R^2$ $= 0.071$)	
	Coef.	P-value	Coef.	P-value	Coef.	P-value
Is Male	0.5000	0.007	0.0492	0.000	0.1607	0.000
Has Driver License			-0.2954	0.000	0.2396	0.000
Age	-0.0251	0.001	-0.0097	0.000	-0.0235	0.000
# Children in Household			0.0162	0.108	0.0466	0.000
Household Size			-0.0131	0.115		
# Workers in Household	0.1529	0.145	-0.0268	0.002	0.0510	0.000
Household Income ($1,000/yr)	0.0032	0.114	0.00197	0.000	0.00286	0.000
Is White	-0.3054	0.168			-0.0482	0.009
Bachelor's Degree or Higher	0.2708	0.134	0.2217	0.000	0.2975	0.000
Works Full Time			-0.2880	0.000	0.1212	0.000
Works Part Time			-0.2215	0.000	0.4418	0.000
Is Student			-0.4332	0.000	0.6608	0.000
Is Unemployed			-0.3553	0.000		
Is Retired	0.6581	0.029	-0.1125	0.000	0.4815	0.000
Is Currently Married			-0.1213	0.000	-0.2232	0.000
# Vehicles in Household			-0.0106	0.188	-0.2135	0.000
Prob. of Car Acquisition Within Year	0.00709	0.004	0.00863	0.000	0.00962	0.000
Distance to Grocery Store			-0.0057	0.000	0.0146	0.000
Distance to Public Transit Stop			-0.0074	0.000	-0.0090	0.000
Distance to Work or School	0.0164	0.077	0.00399	0.000	0.00543	0.000
Distance to Downtown			0.0118	0.000		
Not Disabled			-0.3274	0.000	-0.2624	0.000
Drives Alone to Work			-0.0444	0.002	-0.0433	0.016

Intent to Use Self-Driving Mode, Assuming Vehicle is Capable, by Trip Distance	
	% Respondents
Less than 50 miles	27.8%
Between 50 and 100 miles	29.6%
Between 100 and 500 miles	31.3%
Over 500 miles	24.0%
Never use the self-driving mode	31.2%

Table 3.1, cont.

Willingness to Pay (WTP) Various Purchase/Lease Premiums to make Household's Next Vehicle Full-AV			
	$7,000/$200	$5,000/$140	$2,000/$60
Willing to Pay	23.2%	31.0%	49.5%
Not Willing to Pay	70.7%	62.7%	44.0%
No Future Purchase	6.1%	6.4%	6.5%

WTP Various Amounts to Save 30 min. on a 1-Hour Solo Drive			
	$5.00	$7.50	$10.00
Definitely willing to pay	12.4%	11.3%	5.7%
Probably willing to pay	25.9%	16.4%	9.9%
Not Sure	17.9%	20.7%	24.0%
Probably not willing to pay	16.6%	19.8%	27.5%
Definitely not willing to pay	27.3%	31.9%	32.9%

WTP Various Amounts to Save 1 Hour from a 2-Hour Solo Drive			
	$10.00	$15.00	$20.00
Definitely willing to pay	7.3%	6.8%	4.2%
Probably willing to pay	26.4%	15.9%	10.2%
Not Sure	15.9%	22.6%	27.6%
Probably not willing to pay	16.3%	18.9%	22.0%
Definitely not willing to pay	33.9%	35.8%	36.0%

Likeliness of Engaging More in Each Activity with SAVs Available (by % Respondents)					
	Very Likely	Somewhat Likely	Neither Likely nor Unlikely	Somewhat Unlikely	Very Unlikely
Go places like downtown where parking is an issue	14.7%	26.5%	16.6%	9.3%	32.9%
Use public transit, with SAVs as a backup	7.3%	19.7%	20.5%	14.3%	38.3%
Use bikeshare or walk, with SAVs as a backup	5.4%	17.1%	22.5%	13.8%	41.2%

Table 3.1, cont.

Situations in which Respondents Would Use SAVs (% Respondents)	
To avoid parking fees	38.9%
When personal vehicle is unavailable (maintenance or repairs)	35.1%
As an alternative to driving (e.g. after drinking alcohol)	32.8%
For long trips	23.0%
For short trips	17.1%
Other	1.8%
Never	33.9%

Transportation Choices with SAVs having < 5-min. Response Time, at Different Prices (% Respondents)			
	$2 per mile	$1 per mile	$0.50 per mile
Not own vehicle, rely primarily on SAVs	3.6%	4.3%	4.4%
Not own vehicle, rely primarily on combination of SAVs & other modes	3.6%	3.7%	4.1%
Rely primarily on modes other than SAVs or personal vehicles	10.7%	9.2%	7.5%
Own vehicle(s), but primarily use SAVs	7.5%	8.5%	12.5%
Rely primarily on personal vehicle(s), but use SAVs some	29.3%	31.2%	32.4%
Rely primarily on personal vehicles, no SAV use	44.5%	42.5%	38.3%
Other	0.8%	0.7%	0.8%

SAV Use with < 5 min. Response Time, at Different Prices (average % of miles)			
	$2 per mile	$1 per mile	$0.50 per mile
Average % of miles in SAVs	15.3%	18.6%	24.4%

Change in Household Vehicle Ownership if SAVs Available at $0.50 per Mile			
Add Vehicles(s)	Unaffected	Decrease # Vehicles	Relinquish all Vehicles
9.9%	76.1%	11.7%	2.3%

When would Use DRS if Priced at 40% Discount to Private SAV ($0.60 vs. $1/mi)	
	% Respondents
When Riding Alone	15.6%
When Riding with an Adult Family Member or Friend	26.8%
When Riding with My Child	7.7%
Only at Times of Day I Feel are Safer	16.3%
For Work Trips	9.8%
For Shopping Trips	8.7%
For Recreational Trips	7.6%
For All Trips for which it is Feasible	10.5%
I would Not Use the Service	51.2%

Table 3.1, cont.

Interest in Dynamic Ride Sharing (DRS) or Reasons Why Not Interested					
Very interested	Somewhat interested	No interest in any SAVs	Uncomfortable with strangers	Avoid wait for other riders	Willing to pay for private ride
10.5%	27.5%	27.7%	6.8%	22.3%	20.4%

Policies for Maximum Allowable Empty Travel (average of respondents' opinions)		
	% of total miles	Maximum one-way distance
Privately-owned Vehicles	19.6%	13.9 miles
Shared Fleet Vehicles	21.2%	16.7 miles

Binary Logit for Belief that Empty Vehicle Travel Should Always be Tolled Heavily or Banned ($n = 1426, Pseudo\ R^2 = 0.023$)		
	Coefficient	P-value
Male	-0.2722	0.043
Has Driver License	0.6004	0.071
# People in Household	-0.0861	0.115
Household Income ($1,000/yr)	0.00225	0.105
White	0.4098	0.023
Works Part Time	-0.3149	0.070
Currently Married	-0.2417	0.087
Prob. of Acquiring Car Within Year	-0.0049	0.009

Respondents' Average WTP to Save Driving Time in an Urban or Suburban Setting		
	Driving Alone	Driving with 2 Friends or Family Members
To eliminate 30 min. from 1-hour drive	$4.10	$4.56
To eliminate 1 hour from 2-hour drive	$6.52	$7.04

Respondents' WTP to Have Their Car Drive Itself for 30-Minute Trip					
Cost	Definitely Willing	Probably Willing	Not Sure	Probably Not Willing	Definitely Not Willing
$5.00	12.3%	25.9%	17.9%	16.7%	27.3%
$7.50	11.3%	16.4%	20.7%	19.8%	31.9%
$10.00	5.6%	9.9%	27.1%	24.5%	32.9%

Respondents' WTP to Have Their Car Drive Itself for 1-Hour Trip					
Cost	Definitely Willing	Probably Willing	Not Sure	Probably Not Willing	Definitely Not Willing
$10	7.4%	26.4%	15.9%	16.4%	34.0%
$15	6.8%	15.9%	22.6%	18.9%	35.8%
$20	4.2%	10.2%	27.6%	22.0%	36.0%

Table 3.1, cont.

Powertrain Choice vs. Charge Time for 200-mi Range EV (with equal ownership costs)			
	6-hour charge time	2-hour charge time	30-minute charge time
Diesel Engine	2.5%	3.0%	2.7%
Gasoline Engine	53.9%	47.2%	42.8%
Hybrid-electric	25.6%	24.7%	20.6%
Plug-in Hybrid	8.0%	10.1%	9.5%
Fully-electric	10.1%	15.0%	24.4%

% Respondents with Access to Charging at Home and at Work		
	Charging Access	No Charging Access
At Home	56.6%	43.4%
At Work/School (among commuters)	25.5%	74.5%

Binary Logit models for Factors Affecting Charging Access				
	Home Charging Access (1 = yes) ($n = 1426, Pseudo\ R^2 = 0.102$)		Work/School Charging Access (1 = yes) ($n = 1426, Pseudo\ R^2 = 0.126$)	
	Coefficient	P-value	Coefficient	P-value
Male	0.267	0.0332	0.436	0.005
Has Driver License	0.638	0.0270		
# Children in Household			0.3694	0.000
# People in Household	0.058	0.0627		
Household Income (in thousands)	0.004	0.0083		
White Ethnicity	0.433	0.0058		
Bachelor's Degree or Higher	0.281	0.0274	0.3271	0.062
Employed Full Time			-0.2584	0.177
Currently Married	0.374	0.0051		
# Vehicles in Household	0.218	0.0088	-0.2639	0.016
Prob. of Acquiring Car Within Year	0.011	0.000	0.0148	0.000
Distance to Nearest Grocery Store			0.0392	0.018
Distance to Nearest Transit Stop	0.012	0.033	-0.0178	0.969
No Disability that May Affect Driving			-0.6361	0.079
Drives Alone to Work			-0.461	0.022

Will Consider Owning or Leasing Full-EV despite the Following Situations?					
	Definitely Yes	Probably Yes	Not Sure	Probably No	Definitely No
No home charging space	3.0%	6.9%	32.6%	15.8%	41.8%
No work charging space	20.2%	26.8%	21.0%	17.3%	14.6%
No home or work charging	0.9%	17.0%	16.7%	21.8%	43.6%

Table 3.1, cont.

<table>
<tr><th colspan="8">Mode & Access Choice when Train Stops are 1 mile from Home & within 1 mile of Destination</th></tr>
<tr><td>Drive: 40 mins, $5+</td><td colspan="3">Rail/SAV: 40 min, $8</td><td colspan="3">Rail/other: 30 min, $4 + access mode</td><td>Other</td></tr>
<tr><td>48.2%</td><td colspan="3">19.0%</td><td colspan="3">30.3%</td><td>2.6%</td></tr>
<tr><th colspan="8">Will Drive More or Less if BEV is Primary Vehicle?</th></tr>
<tr><td colspan="2">Definitely More</td><td>Probably More</td><td colspan="2">Same/Not Sure</td><td>Probably Less</td><td colspan="2">Definitely Less</td></tr>
<tr><td colspan="2">9.1%</td><td>16.9%</td><td colspan="2">51.9%</td><td>12.7%</td><td colspan="2">9.3%</td></tr>
<tr><td colspan="3">45.8%</td><td colspan="2">← % Change →</td><td colspan="3">45.5%</td></tr>
</table>

DRS may ease congestion if SAV riders widely adopt DRS for work and school trips, since these are dominated by driving alone during congested times, yet many may share similar destinations (and origin neighborhoods, in the case of home-to-school trips for high school students, for example). However, respondents, on average, opted to share rides with people they do not yet know only 18.78% of their SAV miles, within the range of offsetting the 8% to 20% expected empty of SAVs' VMT (according to simulations by Fagnant and Kockelman 2015, and Loeb and Kockelman 2017), though changes in mode and destination choices, as well as trip generation rates (from those unable to drive now becoming mobile, thanks to self-driving vehicles) may cause additional VMT increase.

41.5% of respondents say their household is actively considering purchasing or leasing a vehicle in the next year, with an average probability of acquiring a vehicle in the next year of 35.3%. 92% of Americans intend to purchase, instead of lease, their next vehicle, and new vehicles are favored over used. 44.0% of all respondents say they "will definitely" sell or donate a vehicle when a new one is acquired, 21.6% are "not sure", and 20.0% probably or definitely will not. For information on timing and selection details of coming vehicle acquisitions, please see Table 2.

Table 3.1 shows interest in, and preferences for, self-driving vehicles if price premium is disregarded, with 32.4% preferring an AV. As this binary logit model's regression results suggest, younger persons (as well as retirees!), non-white males, those with a bachelor's degree or higher, those in higher income households with more workers, and those residing farther from their work or school locations are more likely to choose an AV over an HV – everything else constant - if an AV's added purchase price premium is disregarded.

If using a car that has both self- and human-driven modes, the average respondent expects to use self-driving mode for 35.9% of their distance in that car. As shown in Table 3.1's second set of logit regression results, those without a current driver license, those with a disability, younger persons, unmarried persons, those with higher income and/or more education, and those who live farther from the city center or their work or school expect to use AV mode more, everything else constant. Younger and more educated people, and those with higher disposable incomes may be more comfortable with new technologies. Of course, those with driving restrictions are also more likely to need self-driving technologies.

Respondents were asked their willingness to pay to add full automation, both with and without retaining an option for human driving, to their household's next vehicles acquisition. Respondents indicate an average WTP of $3,117 if a human-driven option is maintained, but only $2,202 without the human-driven option. These WTP averages increase to $3,685 and $3,112 with and without the human-driven option, respectively. It is worth noting that respondents are willing, on average, to pay roughly $1,000 (or $500 with zero values removed) more to retain a human-driven mode on board their new autonomous vehicle.

Table 3.1 also shows respondents' WTP for various specific price premiums, to add self-driving technology to their household's next vehicle purchase or lease. As one would expect, price has a significant effect on adoption rates, ranging from roughly a quarter of vehicle acquisitions at a $7,000 purchase price (or $200/month lease) premium, to roughly a third with a $5,000 premium, to over half of vehicles with a $2,000 premium. However, government policy may make such technologies standard, thanks to the significant social and private benefits of such technology adoption (on the order of $10,000 to $20,000 per AV, according to Fagnant and Kockelman (2015)).

Table 1 also displays respondents' WTP to save 30 minutes from a 1-hour drive (in an urban setting), and to save 1 hour on a 2-hour drive. Interestingly, their WTP does not nearly double between the two pairs of questions; as saved driving time doubles, WTP increases by just 59%, suggesting a declining marginal value of travel time (VOTT) and/or the unlikely nature of strong time penalties (for late arrival, for example) on those taking long-distance (1-hr and 2-hr) trips. Regardless, the implied values of travel time (VOTTs) range from just $6.50 to $9 per driver-hour, which is about half what the USDOT (2015) assumes. Also interesting is that average WTP does not rise by very much (8-11%) when the respondent has friends or family members in the car with him/her.

Respondents were also asked their WTP to save 30 min from a one-hour trip, and to fully automate the driving for 30 min. Their average responses are $6.21 and $5.71, respectively. This suggests that respondents feel they can recoup most (92%) of the value of their travel time if relieved of driving duties, though there may be some bias from the novelty of a car driving itself.

Respondents show more interest in going to denser parts of town, like downtown, once SAVs can eliminate parking costs and hassles (with 42.7% stating they are very or somewhat likely to make these trips more often). The anticipated effect on mode shifts is less substantial, with only 27.0% and 22.5% feeling like they are very or somewhat likely to increase their public transit and bikeshare use, respectively, due to SAV availability as a backup mode.

Avoidance of parking costs was the most popular reason for using SAVs, followed closely by the respondent's own vehicle being unavailable, and then "after drinking alcohol". Each of these three options drew over 30% of respondents. 35% of (population-corrected) respondents indicated they believed that they would never use SAVs.

Somewhat surprisingly, the effects of per-mile SAV pricing on vehicle ownership are low, with those choosing not to own a vehicle rising from just 7.2% to 8.5% as SAV prices fall from $2 to $0.50 per mile. A larger shift occurs in those choosing to own a vehicle but use SAVs as a primary or supplemental mode. Perhaps Americans are so used to vehicle ownership that living without one currently seems like an excessively disruptive shift, though attitudes may well shift over time, as people become accustomed to a sharing economy and, hopefully, the convenience of SAV fleets that respond quickly and reliably to calls for service. The largest group of respondents, in all question scenarios, expect to rely primarily on personal vehicles once AVs and SAVs are available to them, with no SAV use. Notable shifts are evident for those primarily using other modes, indicating that America's mode shift towards SAVs may come largely from non-automobile modes, and thus those currently using public transit, bicycles, and walking.

With SAVs costing just $0.50 per mile (less than the average price of owning and operating a U.S. passenger car for those driving under roughly 20,000 miles per year [AAA, 2017] but feasible under Loeb and Kockelman's [2017] recent simulations of Austin, Texas travel), Table 3.1 suggests only a small decrease in household vehicle ownership. Such hesitation may be due to uncertainty in SAV fleet operators being able to consistently meet respondents' households' needs. Respondents also indicated the highest price per mile they would be willing to pay to use SAVs regularly (at least once per week) to be, on average, $0.44 per mile. This is very close to the $0.45 per mile cost Loeb and Kockelman (2017) estimate in their Austin simulations, and not too far from the $0.59/mile for all-electric SAV (or "SAEV") service they simulated, with response times averaging about 5 minutes per traveler (reflecting all personal travel across the 6-county region, and assuming 1 SAV for every 5 persons making trips within the region that day).

Respondents expect 18.8% of their SAV rides (on average) to utilize the DRS option if DRS travel (with a stranger, someone they have not met before) is priced at a 40% discount, and thus just $0.60 per mile, versus $1 per mile for private use of an SAV. Table 3.1's third set of logit model parameter estimation results reveals that younger males, those with driver licenses, those with at least a bachelor's degree, and those in households of higher income expect to use DRS for more of their SAV rides, everything else constant. Apparently, males and those with more education tend to be more comfortable sharing rides with strangers. Those living farther from work and/or school also expect to use DRS for a higher share of their SAV rides, possibly due to the higher cost of those longer commutes. Nevertheless, results suggest that most Americans do not expect to use DRS under this $0.60 vs. $1/mile pricing scenario. The most popular situation for DRS use appears to be when already traveling with an adult friend or family member. Among the least popular is when riding with a child, suggesting respondents' safety concerns about riding with strangers, which may be alleviated by a trusted adult companion. The second most popular situation for using DRS was "only at times of day I feel are safer," thus reinforcing safety concerns many people may have, at least until they have many good DRS experiences, hopefully in the future sharing economy. DRS is one of the few ways the world's transportation future becomes environmentally sustainable (and relatively non-congesting), while still ensuring much personal travel freedom.

In Table 3.1's hypothetical transit scenario, the rail options attracted more responses than driving (which carried a $5 parking plus vehicle operating costs), though use of SAVs for rail station access appears unpopular. Perhaps the $4 total SAV cost was too high for many respondents, especially if many Americans assume they will still own several cars in an SAV future.

3.1 Policy Questions

Respondents were asked their opinion on empty AV travel. 9.6% of respondents currently feel that empty AVs should be allowed everywhere, regardless of their effect on congestion. In contrast, 24.8% want empty travel banned or tolled heavily in all situations. 16.2% want empty vehicles allowed only at certain times of day, such as uncongested times (and presumably uncongested locations). 8.1% want empty vehicles allowed only in areas not prone to congestion, while 9.8% feel that empty vehicles should be allowed only on certain roadway types. 29.4% of respondents (after population correction, as with all these results) indicated feeling indifferent or unsure, and 2.2% prefer other policies, such as limiting empty driving to trips to access passengers or strictly regulating empty trips to ensure each one is necessary. Thus, many respondents are concerned about congestion effects of empty-vehicle travel. Some may also have safety concerns, and wish to keep them off high-speed roads and/or away from corridors with many cyclists or pedestrians. A follow-up survey is needed to deduce such nuances.

Related to this, the average respondents indicate maximum allowable empty VMT share by AVs should be around 20% of the total, with SAV fleets being permitted a slightly higher percentage than privately-owned vehicles. This presumably reflects respondents' understanding that some empty travel will be needed to enable SAV fleets. However, this negligible difference in averages could suggests to many transport experts that Americans' understanding of such technologies' effects on future roadway operations, especially congestion, is low (which is understandable, given the technology's infancy).

3.2 EV Preferences

As noted in this paper's introduction, the survey also emphasized EVs. Table 3.1 shows that most respondents do not envision driving any more or less when using an electric vehicle, but 26.0% do expect to drive more (perhaps a "rebound effect" from lower per-mile driving costs), and 22.0% expect to drive less (presumably due to range anxiety, or perhaps many EVs' seating and storage limitations).

Assuming a 200-mile range on a new EV and total cost of ownership equal across powertrain types, Table 3.1 shows EV charging times to significantly affect powertrain decisions for respondents' next household vehicle purchase. Rising adoption of fully electric vehicles at faster charge times comes at the expense of gasoline (53.9% at 6-hour vs. 42.8% at 30-minute charge times) and hybrid-electric vehicle (HEV) purchases (25.6% at 6-hour vs. 20.6% at 30-minute charge times)Plug-in hybrid (PHEV) shares rise (from 8.0% to 10.1%) as charge times fall to 2 hours, but falls (to 9.5%) at 30-minute charge times (presumably since a 200-mi-range vehicle with 30-minute charge time is reliable enough for many Americans to shift to a fully-electric EV).

Hybrid-electric vehicle (HEV) purchase decline is minimal between the 6-hour and 2-hour charge-time scenarios, but notable between the 2-hour and 30-minute scenarios. Thus, HEV purchasers may be environmentally-conscious, but require their vehicle be available for long drives, therefore only considering fully-electric vehicles at fast (30-min) charge times. Unsurprisingly, diesel powertrain preferences are insensitive to EV charge time variations. Those seeking large pickup trucks may be less environmentally-conscious and/or perceive EVs as incapable of serving their work needs.

As shown in Table 3.1, 56.6% of respondents report having EV charging capabilities at their home's parking location, a similar finding to a previous study that determined 56% of Americans have the ability to charge an EV at hone (Union of Concerned Scientists, n.d.). Also, 25.5% of workers and students can charge at their work or school location. Those without home-charging access may live in multifamily units, or feel they cannot park near enough to an outlet to charge safely. Some may not be aware of charging availability at work or school.

Logistic regression results in Table 3.1 for predicting EV power access suggest that those with a bachelor's degree (or higher) and those more likely to acquire a vehicle within the next year are more likely to have charging access, both at home and at work or school. Those in household with more vehicles and those residing further from public transit stops are less likely to have (or know of) access to EV charging at work or school, but enjoy a higher likelihood of access at home.

Table 3.1 shows that lacking charging ability at home appears to be a significantly greater hindrance to respondents' willingness to purchase fully-electric vehicles than does a lack of charging ability at work. Presumably Americans are anxious about trying to meet charging needs only at places away from home, or the costs of such charging. Adding charging stations reserved for neighborhood residents) may alleviate this.

3.3 Future Transactions and Travel Behaviors

Respondents were also asked to anticipate vehicle transaction and travel choices in a hypothetical scenario, 10 years in the future. The scenario includes fully self-driving vehicles available at a $5,000 price premium (or $140 above an HV's monthly lease cost). EVs are assumed to have equal life-cycle costs to their gasoline counterparts, and a BEV can be charged to a full 200-mile range in 2 hours at home or 30 minutes at widely available public stations. SAVs cost just $0.65 and $0.40 per mile, for private or DRS rides, respectively.

Under this scenario, respondents expect that 24.5% of their total travel miles will be SAV rides (on average), including rides by themselves or with friends and family, and another 14.8% will be taken as DRS rides (with persons they do not know, inside SAVs). Table 3.2 shows a greater propensity for women to take private SAV rides, and for men to take DRS rides, presumably because men are more comfortable riding with strangers. Disabled persons and those currently without a driver's license are more likely to use both types of SAV service, suggesting mobility benefits from SAVs to those presently facing limitations (but also some demand losses among other, non-driving modes). On average, younger and more educated respondents, and those who live farther from work or school, expect to use SAVs more. As noted earlier, those commuting long distances presumably anticipate greater effort savings from relinquishing driving duties, and younger and more educated people may be more technologically savvy, attracting them to SAVs. Perhaps higher interest from younger people will allow for faster growth in SAV use and accelerate the rate of behavioral change, as people adopt SAV-based travel habits early in life.

Table 3.2: Future Scenario Statistics

Timing of Next Household Vehicle Transactions Under Presented Scenario (by % Respondents)			
	Next Vehicle Acquisition		**Next Vehicle Release**
	Before Scenario	**With Scenario**	**With Scenario**
Within 1 year	31.7%	27.8%	20.9%
In 2 years	22.8%	23.8%	19.9%
In 3 years	12.2%	12.0%	11.1%
In 4 years	6.6%	6.2%	5.4%
In 5 years	9.6%	9.7%	10.8%
In 6 years	2.1%	2.6%	3.0%
In 7 years	0.9%	1.9%	1.8%
In 8 years	1.1%	1.2%	1.5%
In 9 years	0.1%	0.6%	0.4%
In 10 years	3.1%	2.8%	2.0%
In more than 10 years	1.4%	4.3%	5.0%
Never	8.4%	7.1%	18.3%

How Next Household Vehicle will be Acquired Under Presented Scenario (by % Respondents)		
	New	Used
Purchase	50.7%	34.4%
Lease	6.0%	2.2%
(6.7% Respondents indicated their household doesn't ever intend to acquire a vehicle)		

Binary Logit Models for Factors Affecting Next Household Vehicle Purchase Decision						
	Buy (vs. lease) ($n = 1426, Pseudo\ R^2 = 0.042$)		**Used (vs. new)** ($n = 1426, Pseudo\ R^2 = 0.130$)		**AV (vs. HV)** ($n = 1426, Pseudo\ R^2 = 0.106$)	
	Coef.	P-value	Coef.	P-value	Coef.	P-value
Is Male			-0.4433	0.001	0.3338	0.018
Has Driver License	0.3965	0.138	-0.7938	0.020	-0.4182	0.199
Age	0.0216	0.002	-0.0152	0.006	-0.0308	0.000
Household Size	0.2626	0.008	0.0953	0.117		
# Workers in Household	-0.3565	0.009	0.2476	0.004		
Household Income ($1,000/yr.)			-0.0094	0.000	0.00327	0.038
Is White			0.5681	0.001	-0.2989	0.069
Bachelor's Degree or Higher			-0.2970	0.027	0.2904	0.042
Works Full Time	0.4869	0.057	-0.5856	0.000	-0.3385	0.032
Works Part Time	0.4148	0.171				
Is Unemployed					-0.4785	0.020
Is Retired			-0.2836	0.198		
Is Married			-0.2271	0.111	0.2854	0.055
# Vehicles in Household					-0.1671	0.066
Probability of Car Acquisition Within Year			-0.0101	0.000	0.0112	0.000

Table 3.2, cont.

Distance to Grocery Store	0.0726	0.002				
Distance to Work or School			0.0165	0.034		
Distance to Downtown			-0.0097	0.183	0.0131	0.066
Has no Disability					-0.7501	0.003
Drives Alone to Work			-0.3774	0.012		

Continuous Logit Models for Factors Affecting SAV Use				
	% Travel Miles in Private SAVs ($n = 1426, Pseudo\ R^2 = 0.021$)		**% Travel Miles DRS** ($n = 1426, Pseudo\ R^2 = 0.046$)	
	Estimate	P-value	Estimate	P-value
Is Male	-0.0568	0.000	0.0702	0.000
Has Driver License	-0.1093	0.000	-0.1294	0.000
Age	-0.00402	0.000	-0.0125	0.000
# Children in Household			0.0740	0.000
Household Size	-0.0161	0.010		
# Workers in Household	0.1037	0.000	0.125	0.000
Household Income ($1,000/yr)	-0.00023	0.153	0.000856	0.000
Is White	-0.0778	0.000	-0.0869	0.000
Has Bachelor's Degree or Higher	0.1424	0.000	0.1880	0.000
Is Employed Full Time	-0.5695	0.000	0.1512	0.001
Is Employed Part Time	-0.3018	0.000	0.3509	0.000
Is a Student	-0.2267	0.000	0.4638	0.000
Is Unemployed	-0.3101	0.000	0.1622	0.000
Is Retired	-0.1938	0.000	0.3249	0.000
Is Currently Married	0.1253	0.000	-0.0382	0.033
# Vehicles in Household	-0.0706	0.000	-0.1759	0.000
Prob. of Acquiring Car within Year	0.00725	0.000	0.00849	0.000
Distance to Grocery Store	-0.00929	0.000	0.0126	0.000
Distance to Transit Stop			-0.00728	0.000
Distance to Work or School	0.00838	0.000	0.00776	0.000
Distance to Downtown	0.000938	0.197	-0.0022	0.016
Does not Have Disability	-0.2993	0.000	-0.3902	0.000
Drives Alone to Work	0.0461	0.003	-0.0696	0.000

Table 3.2, cont.

Powertrain of Next Household Vehicle Transaction (by % Respondents)		
	Next Vehicle Acquisition	Next Vehicle Release
Gasoline	*63.1%*	*81.2%*
Diesel	2.6%	1.8%
Hybrid-Electric	*15.5%*	4.4%
Plug-in Hybrid	5.1%	0.4%
Fully Electric	8.2%	1.4%
Never Make Transaction	5.5%	10.7%
Body Style of Next Household Vehicle Transaction (by % Respondents)		
	Next Vehicle Acquisition	Next Vehicle Release
Compact	10.2%	8.6%
Coupe	6.7%	7.4%
Sedan	*33.7%*	*34.8%*
Station Wagon	1.1%	2.2%
Minivan	4.9%	5.2%
Crossover Utility Vehicle	9.7%	5.3%
Sport Utility Vehicle	*19.6%*	*17.5%*
Pickup Truck	8.4%	8.5%
No Future Transaction	5.8%	10.6%

Table 3.2 shows when respondents' households intend to complete their next vehicle acquisition and release. Under the scenario, respondents are less likely to plan to never again acquire a vehicle, suggesting sustained personal vehicle ownership despite SAV availability. However, intended vehicle transactions appear to shift slightly later, possibly due an expectation of less personal vehicle use with SAVs available.

As Table 2 shows, respondents' households favor acquiring new over used vehicles, and heavily favor purchasing over leasing, similar to results before the scenario was presented, so AV, EV, and SAV technology availability seems to not largely effect these decisions. Perhaps respondents have difficulty picturing how the technologies may alter their decisions, especially if SAVs alter travel behavior. Those who are more likely to acquire a vehicle within a year are also more likely to choose a new vehicle, so maybe those interested in acquiring a vehicle are optimistic about what they will be able to afford. Younger, married, non-white males with a bachelor's degree but no driver license, who are not unemployed or working full time, live farther from downtown in higher income households with fewer vehicles, and have no disability are more likely to choose a self-driving vehicle over a human-driven one. The probability of acquiring a vehicle within a year shows a strong positive correlation with choosing the self-driving option, so maybe those who are actively researching vehicles are more versed in the benefits of autonomous technologies.

As Table 3.2 shows, most of the vehicles acquired/purchased in this 10-years-forward scenario are still gasoline-based, but fully electric vehicles, PHEVs, and HEVs together comprise 28.8% of intended purchases, compared to 17.6% before the scenario specifics were given (with equal life-cycle costs, $5,000 AV premium, and $0.60 and $0.45/mile SAV and DRS costs). Responses suggest that 24.0% of U.S. households will opt for a fully self-driving vehicle under this scenario, 68.7% will decline that $5,000 automation option, and 7.3% believe their household will never acquire another vehicle.

3.4 Future Home locations

AV and SAV availability may affect household locations, with strong SAV services possibly pulling more households into denser settings, and/or lowered travel burdens pulling many households to the suburbs and exurbs. Table 3.3 notes how the average respondent's household is just over 10 miles from their region's or city's downtown, and 7.6 miles from the nearest public transit stop, effectively eliminating transit as a travel option for many U.S. households and fostering car dependence. SAVs could fill transit gaps, enabling more Americans mobility in suburban and rural settings.

Table 3.3: Responses Regarding Home Location

<table>
<tr><th colspan="7">Average Distance from Respondents' Homes to Select Locations (Min = 0, Max = 30)</th></tr>
<tr><td colspan="4"></td><td>Mean</td><td>St. Dev.</td><td>Median</td></tr>
<tr><td colspan="4">To Nearest Grocery Store</td><td>5.01 miles</td><td>5.77 miles</td><td>3.23 miles</td></tr>
<tr><td colspan="4">To Nearest Public Transit Stop/Station</td><td>7.57 miles</td><td>10.30 miles</td><td>2.07 miles</td></tr>
<tr><td colspan="4">To Respondents' Job or School</td><td>7.91 miles</td><td>9.56 miles</td><td>3.93 miles</td></tr>
<tr><td colspan="4">To Nearest City's Downtown</td><td>10.22 miles</td><td>9.18 miles</td><td>7.31 miles</td></tr>
<tr><th colspan="7">Expected Residence Type of Those Households Intending to Move (by % Respondents)</th></tr>
<tr><td>Detached Single Family</td><td>Duplex</td><td>Townhome</td><td>Multi-Family ≤ 6 Floors</td><td>Mixed Use ≤ 6 Floors</td><td>Multi-Family ≥ 7 Floors</td><td>Other</td></tr>
<tr><td>60.6%</td><td>1.9%</td><td>8.8%</td><td>17.3%</td><td>0.7%</td><td>5.2%</td><td>5.4%</td></tr>
<tr><th colspan="7">% of Households that Expect to Shift toward Each Residence Type if AVs & SAVs are Available</th></tr>
<tr><td>15.5%</td><td>1.0%</td><td>3.2%</td><td>2.2%</td><td>1.8%</td><td>0.2%</td><td>0.6%</td></tr>
<tr><td colspan="7">70.7% of household choices would not be affected, & 4.7% would but the respondent is not sure how.</td></tr>
<tr><th colspan="7">Expected Residence Type of Those Households Intending to Move if AVs & SAVs are Available</th></tr>
<tr><td>59.5%</td><td>2.5%</td><td>9.9%</td><td>15.9%</td><td>2.1%</td><td>4.6%</td><td>5.4%</td></tr>
</table>

24.4% of Americans claim their household is actively considering moving soon, of which 60.6% expect to move within the next year. 29.3% of those actively considering moving plan to move closer to the city center, while 38.0% plan to move farther from the city center (and 32.7% expect to stay the same distance away). AV and SAV availability is found to influence 14.8% of these near-term movers, pulling them closer to the city center than they otherwise would, while another 9.7% feel they are likely to move farther away from the city center than they otherwise would. 16.4% of near-term movers believe such technologies will impact their new location choice, but not their distance from the city center. The remaining 59.1% (of near-term movers) anticipate no effect on their location choice. Presumably many respondents expect better SAV service in denser urban areas and will value the convenience this offers. Additionally, some respondents may currently live away from the city center in order to avoid certain vehicle-related challenges (such as car storage/parking). Some may be less averse to living in these areas if they have reliable and rapid alternatives to private vehicles. Some may feel they can compensate for higher land rents of more central locations by lowering their transportation costs via SAVs and DRS.

Table 3.3 also illustrates how availability of AVs and SAVs appears to influence dwelling unit type, with respondents shifting toward duplexes, townhomes, and mixed-use complexes, while single-family homes and other multifamily housing types lose popularity. Those reducing car ownership may see more value in mixed-use settings, thanks to (presumably) lower overall transport costs.

3.5 Demographics

Table 3.4 shows summary statistics of the demographics questions. The answers to these questions are used to produce individual and household weights, and as explanatory variables in the regression models presented in this chapter and in Part 2. Demographics are corrected to match the U.S. population before producing the summary statistics presented in this chapter and the simulation outputs presented in Part 2. For all regression models, the mid-point of each income range is used, and a value of $225,000 is used for the “greater than $200,000” category.

Table 3.4: Summary Statistics of Demographics (Unweighted)

	Mean	St. Dev.	Median	Max
Average # of Members in Household	2.624	1.311	2	10
Average # of Children in Household	0.5856	0.9456	0	6
Average # of Workers in Household	1.239	0.9666	1	7
% Male	37.24%			
% With Driver License	95.09%			

Age Distribution

18 to 24	25 to 34	35 to 44	45 to 54	55 to 64	65 and up
5.96%	21.46%	19.64%	16.41%	17.11%	19.43%

Race/Ethnicity

Hispanic	Asian	Black	Native American	White	Mixed
4.70%	4.21%	6.73%	0.49%	82.47%	1.40%

Level of Education Achieved

No High School	High School	Some College	Associates Degree	Bachelors Degree	Masters or Higher
1.47%	16.55%	22.44%	14.38%	28.33%	16.83%

Employment Status

Employed Full-Time	Employed Part-Time	Student, Working	Student, not Working	Unemployed	Retired	Disabled
38.22%	17.11%	1.04%	1.54%	15.85%	21.67%	4.21%

Marital Status

Single	Married	Divorced	Widowed
27.56%	56.66%	11.57%	4.21%

Annual Household Income

Less than $10,000	3.65%
$10,000 to $19,999	7.50%
$20,000 to $29,999	11.15%
$30,000 to $39,999	10.80%
$40,000 to $49,999	8.63%
$50,000 to $59,999	10.24%
$60,000 to $74,999	12.06%
$75,000 to $99,999	15.50%
$100,000 to $124,999	8.14%
$125,000 to $149,999	5.75%
$150,000 to $199,999	4.21%
More than $200,000	2.31%

Chapter 4: Conclusions for Part One

This recent survey offers a wide range of valuable new information for anticipating transport futures and crafting policies to enhance U.S. travel choices. For example, younger and better educated respondents show more intention to use EV, AV, SAV and DRS technologies. However, most U.S. households appear unwilling to reduce vehicle ownership, even those with members who expect to regularly use SAVs. This suggests that a significant cultural shift may be needed to reduce private vehicle ownership. Government agencies may need to consider additional incentives if they wish to reduce private vehicle ownership in their jurisdictions.

These results are useful to manufacturers and potential shared fleet operators for pricing and marketing decisions. Government agencies, including public transit providers, can benefit from understanding evolving travel choices and land use patterns, including demographic disparities, to craft policies and transit service to equitably serve the population. These results may help transportation departments and MPOs model future transportation demand and plan infrastructure projects. To reduce congestion from added VMT, empty AV travel may need to be statutorily limited below the level of the average public opinion. Alternatively, significant public support exists for heavily tolling empty travel in all situations, so a tolling scheme may be used to limit empty travel, which may be effective for fleets but cause equity disparities among private owners.

These results are limited by their reliance on stated preference data, since AVs and SAVs are not yet available for purchase or regular use. Respondents may have many false expectations of these technologies, and actual decisions will vary, as more demonstrations get underway, SAVs become accessible via ride-hailing apps, friends and family members report favorable (or unfavorable) impressions, AV technology becomes commonplace, and/or self-driving cars deliver a safety record that clearly beats human drivers. As Bansal and Kockelman's (2016) fleet evolution scenarios simulated (without reflecting EVs and SAVs), WTP is likely to rise, as technology prices fall. But prices will start high and early access will be quite limited. A natural next step is simulating fleet evolution and AV use statistics, to get a better sense of what levels and shares of future VMT will be in AV mode, in the U.S. and around the world.

PART 2: AMERICA'S FLEET EVOLUTION IN AN AUTOMATED FUTURE

Chapter 5: Introduction to Part Two

Autonomous, electric, and shared vehicle technologies are poised for rapid growth. Electric vehicles (EVs) have existed since the late 19th century, and continuing battery-cost reductions are increasing their attractiveness. Very-short-term rentals in urban areas launched the relatively new newer concept of shared vehicles. Ride hailing has emerged in just the last few years, enabled by cell phones, with their GPS. Fully self-driving vehicles, once they become available, will impact these options and others (Fagnant and Kockelman 2016).

EVs can reduce emissions and negative health impacts in many power-generation settings, compared to conventional internal combustion vehicles. Reiter and Kockelman (2017) find a typical EV to generate about half the emissions externalities as that of a gasoline vehicle in Texas cities. Nichols et al. (2015) estimated EVs in Texas to lower emissions of every analyzed pollutant except SO_2, which increases due to the burning of coal for electricity generation. EVs would lower emissions of all pollutants if generation is shifted away from coal and toward cleaner sources. Many national, state, and local governments have initiatives to accelerate EV adoption, seeking air quality, climate change, and energy-security benefits. As long as generation is sufficient to meet demand, revenues from EV charging may minimize electricity rate increases, while EV owners may be able to save money via overnight charging (Tonachel 2017).

Shared and autonomous vehicle technologies may alter vehicle ownership and demand for various transportation modes. Perrine and Kockelman (2017) indicate AV travel may partially replace airline travel, while generating more short-distance travel. It stands to reason that intercity rail and bus modes may also be affected. Fagnant and Kockelman (2014) found that each SAV may replace 11 personal vehicles, but increase VMT by 10%, while decreasing overall emissions. If SAVs entice people to give up personal vehicles, the vehicle fleet may shrink, necessitating less parking space. Increased VMT may drive higher vehicle production rates, since SAVs would accumulate miles quickly.

Previous work to understand U.S. fleet evolution has included simulation analysis. Bansal et al. (2015) modeled light-duty fleet evolution in Texas regarding fuel efficiency and hybrid-electric vehicle adoption. They used existing Texas Department of Motor Vehicle information to estimate the effects of built environment and demographic factors on choice of hybrid-electric and fuel-efficient vehicles and calibrate their simulation. Paleti et al. (2011) simulated vehicle ownership and travel mileage by vehicle type over time, based on a sample of Californians. They found annual VMT to be higher for larger vehicles. The also analyzed vehicle attributes that may affect choice to purchase electric vehicles.

Kieckhäfer et al. (2014) used a hybrid simulation approach, integrating a system dynamics model with an agent-based discrete choice model, to estimate the evolution of electric vehicle market share. Their simulation modeled the German vehicle market, and found that considering individual consumer choices is necessary for an accurate result. Their findings include an expected BEV fleet share of about four percent, PHEV fleet share of about nine percent, and HEV fleet share of about twelve percent in the year 2029.

Bansal and Kockelman (2017a) surveyed 2,167 Americans to calibrate a 30-year simulation of Americans' adoption of connected and autonomous vehicle technologies, ending in 2045. Their study included all levels of automation, and looked at multiple scenarios incorporating different technology price reductions and increases in the population's willingness to pay for the technologies. The study did not include electric vehicles, or shared vehicles.

Musti and Kockelman (2011) microsimulated fleet evolution for 25 years in Austin, Texas, focusing primarily on plug-in hybrid-electric vehicles, calibrated with existing data, as well as a survey of Austinites tailored to understanding fleet evolution. Vehicle choice in the questionnaire was conducted via a series of choices between specific vehicles. This approach may result in biases, such as brand loyalty, dislike of a particular vehicle model for reasons other than its powertrain or fuel efficiency, or differences in familiarity between models. This study simulated scenarios including a feebate program to incentivize purchasing HEVs and PHEVs, to help understand what factors may influence future ownership of PHEVs.

Paul et al. (2011) used a stated and revealed preference survey to simulate fleet make-up, usage, and resulting GHG emissions in a synthetic population over a 25-year period. The study analyzed how various factors, such as fuel prices, PHEV pricing, feebate policies, and demographic factors. Higher gas prices provided the greatest reduction in GHG emissions and VMT. Higher density development also produced significant reductions in both, while lower PHEV pricing resulted in higher PHEV ownership rates, but increased VMT, and negligible impact on GHG emissions.

While each of these studies provide valuable estimations of fleet evolution, none of them analyzes electric, autonomous and shared vehicle technologies in a single fleet evolution simulation. This study does that, based on a recent survey tailored to the simulation.

Chapter 6: Methodology for Part Two

This study is centered on a simulation, developed using MATLAB, which is calibrated with regression models of the responses to the survey described in Part 1. Regression models include logit, multinomial logit, ordered probit, and weighted least squares, and regression results are shown in Table 6.1. The regressions here are modeled with the unweighted sample. The household weights are applied at the end of the simulation to intrerpret the simulation results as a representation of the U.S. population by making the demographics of the simulated households match that of the population. The moving direction decision is based on two survey questions, which are discussed in Part 1.

Respondents whose households are considering moving are initially asked where their houshehold intends to move in relation to the city center (without mention of AVs or SAVs. Respondents can answer “closer to the city center”, for which they are assigned an initial value of 2, “same distance to the city center”, for which they are assigned an initial value of 3, or “farther from the city center”, for which they are assigned an initial value of 4. Respondents are then posed an additional question, asking them how the availability AVs and SAVs would influence where their houshelod would choose to move. Respondents may answer “no effect” or that their household would choose a location the same distance from the city center as they otherwise would have. These households retain their initial value. Respondents can also answer “closer to the city center than their household otherwise would have”, for which one is subtracted from its initial value, or “farther from the city center than their household otherwise would have”, for which one is added to its initial value. Thisresults in a range of possible values from 1 (two “units” closer to the city center) to 5 (two units farther from the city center). Since respondents never indicate how far towards or away from the city center they intend to move, a value must be assumed for the simulation. For this reason, it was necessary to choose reasonable values. A value of 1 is chosen to indicate moving 50% closer to the city center, a value to indicates moving 25% closer to the city center, a value of 3 indicates no change in distance to the city center, a value of 4 indicates moving 25% farther from the city center, and a value of 5 indicates moving 50% farther from the city center.

Table 6.1: Regression Coefficients for Annual Application of Household Moving Choices

Move Decision This Year (Binary Logit, n=1426, Pseudo R^2 = 0.1314)		
Parameter	**Estimate**	**t-statistic**
Intercept	1.0755	2.48
Male	-0.2567	-1.53
Age	-0.0435	-7.23
HHChildren	0.2208	1.75
HHSize	-0.2224	-2.07
HHWorkers	0.2817	2.79
HHVehicles	-0.4504	-4.14
VehPurchYearProb	0.0104	4.56
PTDist	0.0147	2.00
NoDisability	-0.4490	-1.73
DAtoWork	-0.3519	-2.13
Moving Direction Decision (Ordered Probit, y = 1 = 50% closer, 2 = 25% closer, 3 = same distance, 4 = 25% farther away, 5 = 50% farther away, n = 365, Pseudo R^2= 0.0418, σ_ε=1)		
Parameter	**Estimate**	**t-statistic**
Ψ_5 (threshold)	-1.2022	-3.53
Ψ_4 (threshold)	0.0243	0.07
Ψ_3 (threshold)	0.8994	2.66
Ψ_2 (threshold)	1.4854	4.36
Male	-0.3690	-2.91
HHChildren	-0.2413	-2.85
HHSize	0.1229	1.72
FullTime	-0.7068	-2.61
PartTime	-0.7865	-2.70
Student	-0.7490	-2.24
Unemployed	-0.7614	-2.74
Retired	-0.6409	-2.08
HHVehicles	0.1085	1.51
VehPurchYearProb	-0.0023	-1.33
WorkSchoolDist	-0.0109	-1.71
NoDisability	0.2959	1.60
DAtoWork	0.1670	1.32

Table 6.2: Regression Coefficients for Annual Application of Household Vehicle Transaction Choices

Decision to Acquire a Vehicle (Binary Logit, n = 1426, Pseudo R^2 = 0.0420)		
Parameter	**Estimate**	**t-statistic**
Intercept	-0.5018	-1.25
Male	0.4634	3.57
License	-0.6230	-1.71
HHChildren	0.2400	3.71
HHIncome	0.0042	3.24
White	-0.2903	-1.81
Student	0.4467	1.26
Unemployed	0.3919	2.17
PTDist	-0.0161	-2.48
DAtoWork	0.1583	1.23
AgeOldest	-0.0059	-0.64
Buy (vs. Lease) Decision (Binary Logit, n = 1426, Pseudo R^2= 0.0419)		
Parameter	**Estimate**	**t-statistic**
Intercept	0.0142	0.03
License	0.5886	1.48
Age	0.0216	3.11
HHSize	0.2628	2.64
HHWorkers	-0.3574	-2.62
FullTime	0.4862	1.91
PartTime	0.4140	1.37
GroceryDist	0.0725	3.03
Used (vs. New) Vehicle Decision (Binary Logit, n = 1426, Pseudo R^2 = 0.1304)		
Parameter	**Estimate**	**t-statistic**
Intercept	1.7654	3.91
Male	-0.4482	-3.28
License	-0.7955	-2.33
Age	-0.0151	-2.70
HHSize	0.0952	1.56
HHWorkers	0.2478	2.85
HHIncome	-0.0094	-5.43
White	0.5724	3.26
BachelorsDegree	-0.3052	-2.27
FullTime	-0.5810	-3.73
Retired	-0.2878	-1.31
Married	-0.2338	-1.64
VehPurchYearProb	-0.0102	-5.31

Table 6.2, cont.

WorkSchoolDist	0.0164	2.11
DTDist	-0.0097	-1.32
DAtoWork	-0.3764	-2.51
Dens	0.5027	1.61
Decision to Release a Vehicle (Binary Logit, n = 1426, Pseudo R^2 = 0.1354)		
Parameter	**Estimate**	**t-statistic**
Intercept	-2.1714	-3.90
License	-0.7256	-1.61
HHSize	-0.1589	-2.40
White	0.2737	1.41
Retired	0.3103	1.47
Married	0.2221	1.37
VehPurchYearProb	0.0259	11.99
PTDist	-0.0141	-1.83
NoDisability	0.4181	1.28
DAtoWork	0.3242	1.98
AgeOldest	-0.0065	-0.60

Table 6.3: Regression Coefficients for Annual Application of Household SAV Use Choices

Percent of Overall VMT as DRS Decision (Continuous Binary Logit, n = 1426, Pseudo R^2 = 0.0461)		
Parameter	**Estimate**	**t-statistic**
Intercept	-1.2387	-20.99
Male	0.0705	4.35
License	-0.1300	-3.62
Age	-0.0125	-18.49
HHChildren	0.0733	8.43
HHWorkers	0.1254	13.02
HHIncome	0.0009	4.70
White	-0.0866	-4.61
BachelorsDegree	0.1868	11.32
FullTime	0.1508	3.25
PartTime	0.3469	7.33
Student	0.4641	7.91
Unemployed	0.1637	3.58
Retired	0.3221	6.84
Married	-0.0397	-2.22
HHVehicles	-0.1760	-16.76
VehPurchYearProb	0.0085	38.68

Table 6.3, cont.

GroceryDist	0.0126	8.63
PTDist	-0.0072	-8.10
WorkSchoolDist	0.0077	8.41
DTDist	-0.0022	-2.40
NoDisability	-0.3916	-14.50
DAtoWork	-0.0676	-3.67
Dens	0.0601	2.31
Percent of Overall VMT as Private SAV Decision (Continous Binary Logit, n = 1426, Pseudo R^2 = 0.0205)		
Parameter	**Estimate**	**t-statistic**
Intercept	-0.4622	-9.30
Male	-0.0574	-4.25
License	-0.1112	-3.66
Age	-0.0040	-7.05
HHSize	-0.0164	-2.62
HHWorkers	0.1039	11.61
HHIncome	-0.0002	-1.39
White	-0.0772	-4.77
BachelorsDegree	0.1419	10.36
FullTime	-0.5706	-16.40
PartTime	-0.3103	-8.77
Student	-0.2257	-4.73
Unemployed	-0.3086	-9.18
Retired	-0.1951	-5.70
Married	0.1238	8.31
HHVehicles	-0.0696	-8.07
VehPurchYearProb	0.0072	39.45
GroceryDist	-0.0092	-7.93
WorkSchoolDist	0.0083	10.82
DTDist	0.0010	1.34
NoDisability	-0.3016	-12.73
DAtoWork	0.0496	3.20
Dens	0.1305	5.46

Table 6.4: Regression Coefficients for Annual Application of Household Willingness to Pay

WTP for AV without HV option (OLS, n = 1426, R squared = 0.1727)		
Variable	**Parameter**	**t-statistic**
Intercept	4814.4	8.12
Male	523.80	2.45
Age	-39.199	-5.23
HHChildren	372.18	3.02
White	-647.87	-2.40
BachelorsDegree	439.35	2.15
Unemployed	-821.90	-2.87
Married	534.16	2.32
HHVehicles	-443.81	-3.42
VehPurchYearProb	25.581	8.64
GroceryDist	67.124	3.73
DTDist	-16.838	-1.49
NoDisability	-1176.8	-2.99
WTP for AV with HV option (OLS, n = 1426, R squared = 0.2025)		
Variable	**Parameter**	**t-statistic**
Intercept	5142.4	8.94
Age	-53.875	-7.22
HHChildren	210.16	1.73
HHIncome	7.3388	3.20
Student	-1127.4	-1.87
Unemployed	-1127.3	-4.01
Married	544.63	2.35
HHVehicles	-271.91	-2.07
VehPurchYearProb	31.059	10.74
GroceryDist	34.517	1.83
PTDist	-14.953	-1.41
NoDisability	-837.69	-2.17

Table 6.5: Regression Coefficients for Annual Application of Household VMT

Overall Annual VMT Decision (OLS, n = 1426, R squared = 0.2131)		
Variable	**Parameter**	**t-statistic**
Intercept	452.51	0.65
Male	519.49	1.75
License	2807.1	4.15
HHChildren	475.81	2.94
HHIncome	5.9926	1.82
White	866.85	2.36
FullTime	1284.5	3.06
PartTime	743.22	1.58
Retired	822.94	1.85
Married	796.22	2.50
HHVehicles	468.50	2.51
VehPurchYearProb	10.278	2.50
GroceryDist	58.939	2.39
WorkSchoolDist	90.846	5.39
DAtoWork	1679.4	4.84

Table 6.6: Regression Coefficients for Annual Application of Powertrain Choices on Vehicle Acquisitions

Powertrain Decision (Multinomial Logit, Gasoline as Baseline, n = 1426, Pseudo R^2 = 0.0994)								
	Battery-Electric		Plug-in Hybrid		Hybrid-Electric		Diesel	
Variable	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**
Intercept	-1.3754	-0.90	1.5322	1.31	2.4870	2.20	0.9819	0.78
Male	-0.6774	-1.30	-1.4769	-3.65	-1.0204	-2.62	-1.0120	-2.28
Age	0.0111	0.51	0.0128	0.76	0.0215	1.30	0.0192	1.07
HHChildren	-1.1133	-2.61	-0.6548	-2.08	-0.3132	-1.01	-0.5575	-1.61
HHSize	0.6196	1.83	0.2421	0.86	0.0106	0.04	0.1476	0.49
BachDegree	-0.3376	-0.62	-0.4072	-1.01	-0.3438	-0.86	-0.8427	-1.86
Married	0.0102	0.02	-0.2124	-0.46	-0.6301	-1.36	-0.3815	-0.75
VehPurYrPr	-0.0037	-0.44	-0.0191	-3.04	-0.0168	-2.71	-0.0134	-1.96
GroceryDist	0.0031	0.07	-0.0495	-1.52	-0.0854	-2.39	-0.0618	-1.66
PTDist	-0.0201	-0.53	0.0288	1.22	0.0095	0.39	0.0338	1.33
WrkSchDist	-0.0210	-0.72	-0.0311	-1.43	-0.0274	-1.27	0.0061	0.27
NoDisabil	0.3269	0.42	0.9088	1.49	0.1166	0.21	0.4334	0.68
DAtoWork	0.3798	0.71	0.4714	1.17	0.5808	1.44	0.0239	0.05

Using the initial regression values, the simulation produces unrealistic vehicle purchase and release numbers, resulting in roughly a tripling of per-household vehicle ownership by year

2050. To correct for this, the alternative-specific constant (ASC) values are adjusted to produce more realistic results. This is likely due to errors in estimation by respondents of when future vehicle purchases and releases will occur. For instance, respondents indicated an average likelihood of their household acquiring a vehicle in the coming year that was roughly double what is statistically expected for American households to actually acquire. To accomplish this, the ASC value for the vehicle purchase decision is adjusted until the per-household vehicle purchase rate in the early years of the simulation matches the 17.1 million annual vehicle purchases expected to be made in 2017 the United States (Associated Press, 2017). The ASC for the vehicle release decision is then adjusted until the overall rate of change of per-household vehicle ownership matches that of recent years in the United States, as calculated from vehicle ownership per household figures given by Statista (2016). For this process, values were scaled based on the count of 125.82 million households in the United States in 2016 (Statista, 2017). While this provides a more accurate starting point for the simulation, it does not lock vehicle purchases and releases throughout the simulation to predetermined values, as they are still affected by changes in the explanatory variables used in the regression models.

Demographics, such as household size and income, do not change during the simulation, and the overall number of households is held constant to eliminate population change as a factor. Thus, all results assume a constant US population over time, rather than adding that additional layer of prediction (of changes in income, household size, etc.). Each respondent's age estimate[1] is used as an explanatory variable in the regression models. While there are multiple people in many households, the respondent's age is an indication of the age of the adults in his/her household. Age increases with every simulation year, until age 80 is reached, at which time the age is changed to 18 years old. Since respondents give age as a range, it is necessary to distribute the households within their age range to a reasonable number of households to roll over from an age of 80 to an age of 18 in every simulation year, instead of all households in each age range

[1] Respondents did not provide their exact age, but chose a range or age category. These categories are 18-24 years of age, 25-34, 35-44, 45-54, 55-64, and 65 or more, Rather than choosing the mid-range age for all respondents, ages were assigned uniformly in the range, to allow a smooth and more realistic progression of aging and household shifts over time.

rolling over in the same year. To accomplish this, each household's age is distributed according to a random uniform distribution within the age range provided by its respondent.

Model predictions of vehicle ownership, VMT by mode and vehicle type, and average distance from home locations to the city center are reported in Tables 7.1 through 7.15 in the following chapter for the initial year 2017, then every five years, beginning in year 2020. Average annual VMT falls with vehicle age, so the following equation, from NHTSA (Lu, 2006) is used to assign a predict an initial annual VMT to each vehicle, based on its age (A):

$$VMT_{Initial} = 14476.36 - 232.8491 * A - 13.21949 * A^2 + 0.3672131 * A^3 \quad (2)$$

where A is the age of each simulated vehicle, over time. Each household's DRS VMT and private SAV VMT is subtracted from the household's total VMT, and the remaining "private vehicle VMT" is distributed to each household vehicle proportional to each vehicle's initial (or NHTSA-estimated) VMT. A flowchart outlining the simulation process for each year is shown in Figure 6.1.

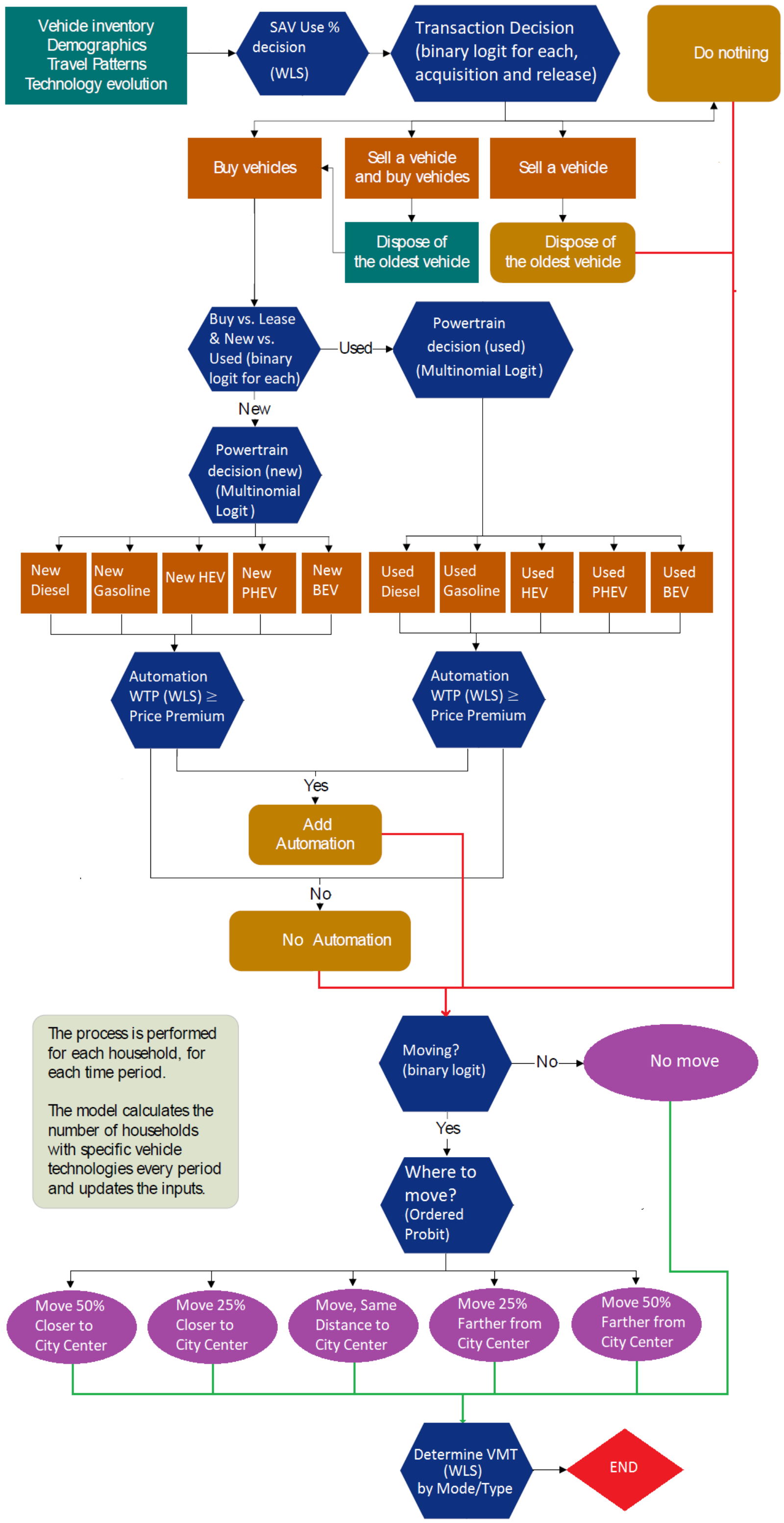

Figure 6.1: U.S. Fleet Evolution Simulation Flowchart

Chapter 7: Simulation Results

7.1 Fleet Composition and VMT

Six scenarios were simulated, in addition to a business as usual scenario where AVs and SAVs are not available, with two scenarios of WTP for full-AV technology each paired with three scenarios of technology price decline. The two WTP scenarios are based upon the survey responses for WTP with and without the option to retain a human-driving option, respectively. The average WTP values given by the survey respondents are $3,252 and $2,783 to add AV technology to their household's next vehicle, with and without retaining an option for human-driving, respectively. WTP values increase over the course of the simulation. A concave function is likely the most realistic for WTP increase, since WTP is currently low, likely due to the lack of familiarity Americans have with this not-yet-available product. Upon availability, Americans will be able to become more familiar with the technology, so it makes sense that WTP will increase relatively rapidly, before beginning to level-off as understanding of the technology becomes ubiquitous. This ruls out a linear or annual percentage increase. For that reason, WTP for all scenarios follows the equation:

$$WTP_{i,j} = WTP_{model,i,j} * \left(1 + \sqrt{\frac{t}{4}}\right) \quad (3)$$

where $WTP_{i,t}$ represents the WTP value returned by the regression model in year *t* for respondent or household j. This equation is used because it results in average WTP values rising to around $10,000 to $13,000 by year 2050, as shown in Figure 7.1, which may be reasonable as AV technology becomes viewed as universal and necessary for new vehicle purchases. This parabolic curve results in a 50% rise in WTP in the first year, which drops to 13.8% in the second year, and 7.2% in the third year. The annual increase falls below 3% in year 2028, below 2% in year 2025, and ends at 1.1% in year 2050.

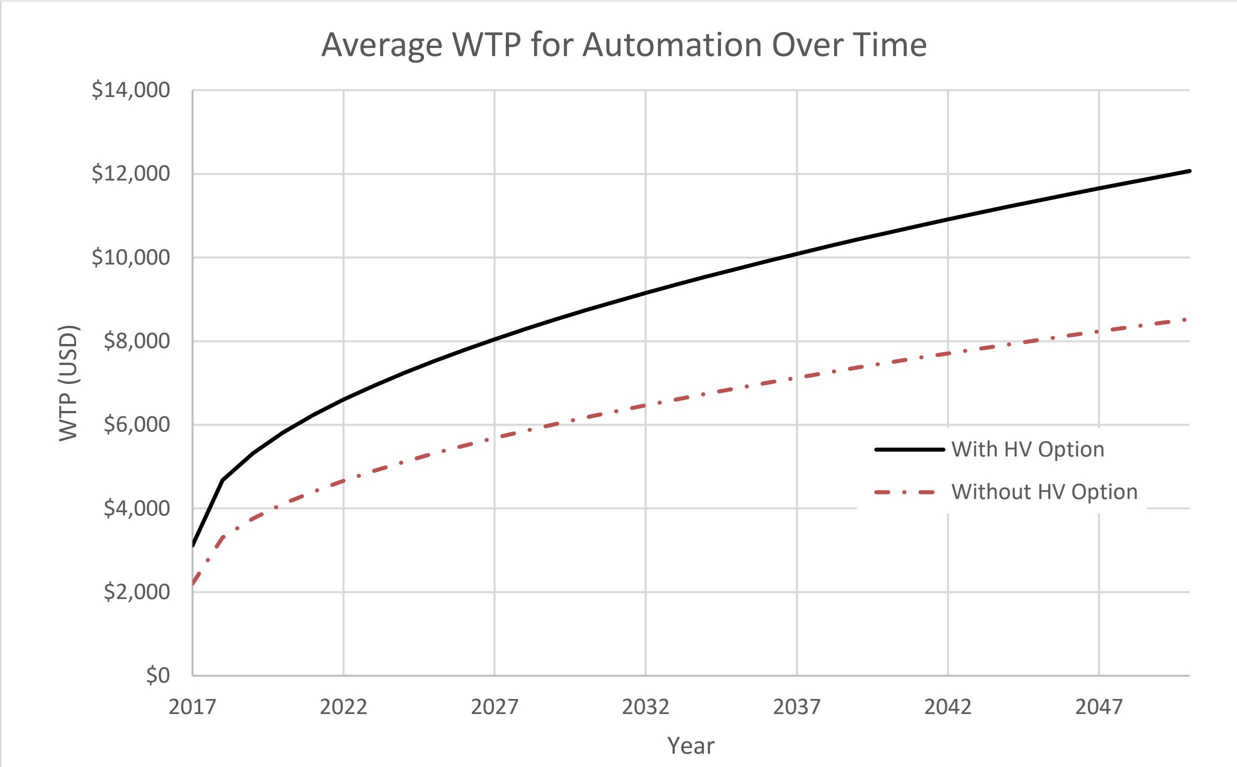

Figure 7.1: Average Willingness to Pay for Automation Over Time.

For all scenarios, SAV availability begins in year 2020, but at high prices to represent their limited initial availability (e.g., in New York City, Boston, Pittsburgh, and San Francisco markets first, perhaps) and somewhat higher actual prices. SAV prices (per mile of passenger travel) drop at a rate of 15 percent per year to simulate their increasing availability, as well as an actual price drop. By year 2050, SAV prices reach a "rock-bottom" price of $0.65 per mile for private SAV rides and $0.40 per mile for DRS rides, which presumes heavy competition and universal availability. The AV technology purchase price premium is initially set to $20,000 for all scenarios, and is modeled for three different scenarios: dropping by five percent annually, dropping by 7.5 percent annually, and dropping by ten percent annually. These price declines result in year 2050 technology premiums of $3,690, $1,526, and $618, respectively. Each technology premium scenario is paired with each WTP scenario to generate the six total scenarios in this analysis. While a $618 technology price premium may seem low for year 2050, it is possible that features such as connectivity and certain safety features (which would inherently be part of a self-driving vehicle) may be required on new vehicles by then, which could raise the price of human-driven vehicles enough that the additional expense for a self-driving vehicle may drop faster than does the cost to produce the equipment and software that would be necessary to upgrade from currently-available vehicles. Figure 7.2 shows the technology premiums over the timespan of the simulation.

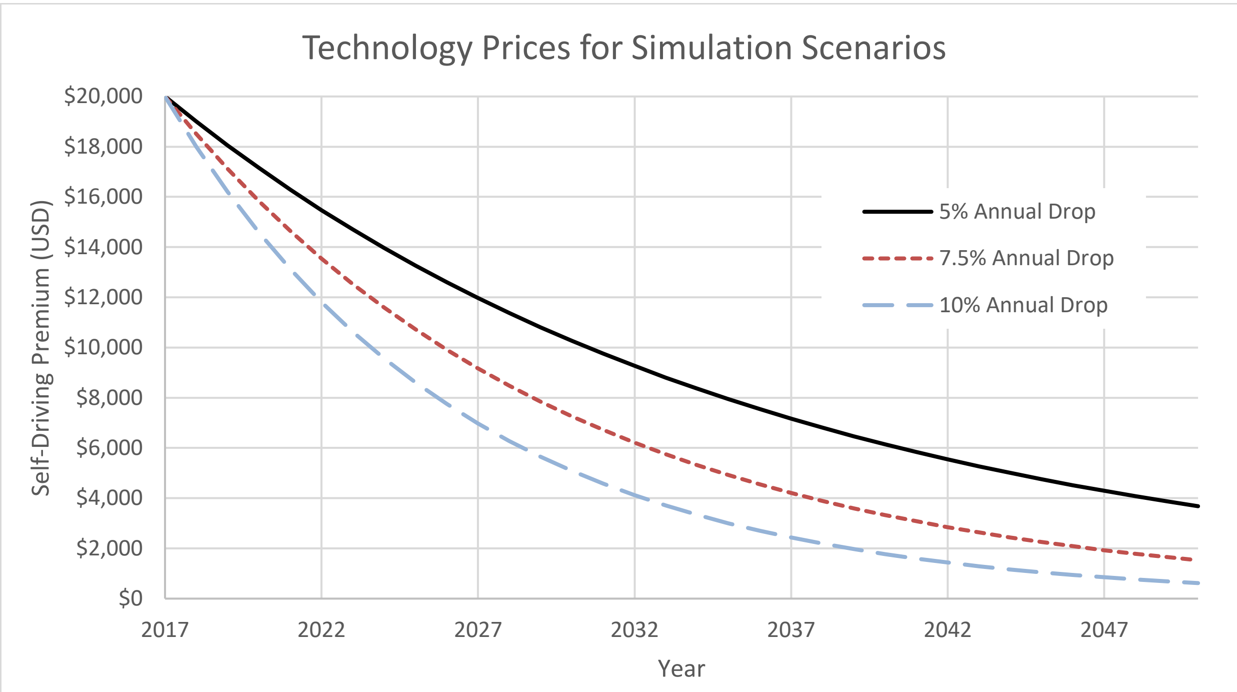

Figure 7.2: Technology Prices for Simulation Scenarios.

7.1.1 Business as Usual Forecasts

A business as usual (BAU) scenario is simulated, in which AVs and SAVs are not available. Private vehicle ownership results for this scenario are shown in Table 7.1.

Table 7.1: U.S. Privately-Owned Fleet Composition without AV & SAV Availability (BAU Case)

Year	Vehicles	% AV	% HV	% Diesel	% Gasoline	% HEV	% PHEV	% BEV
2017	222.1 M	n/a	100%	1.9%	95.1%	2.5%	0.2%	0.4%
2020	219.7 M	n/a	100%	2.0%	74.4%	12.2%	9.4%	2.0%
2025	230.7 M	n/a	100%	2.6%	46.9%	24.6%	22.1%	3.7%
2030	235.6 M	n/a	100%	2.4%	25.9%	33.6%	32.6%	5.5%
2035	249.1 M	n/a	100%	2.5%	13.2%	38.5%	39.5%	6.3%
2040	245.7 M	n/a	100%	2.5%	6.3%	41.9%	42.4%	6.9%
2045	247.9 M	n/a	100%	2.2%	6.7%	42.1%	42.1%	6.8%
2050	248.8 M	n/a	100%	2.2%	6.4%	43.2%	42.3%	5.9%

While the BAU scenario keeps all future vehicle ownership human-driven, significant changes in the U.S. fleet's powertrain makeup are seen. Hybrid-electric and plug-in hybrid vehicle adoption rises rapidly, while battery-electric adoption also rises, but at a lower rate. These increases in adoption correspond with a sharp decrease in gasoline vehicles in the fleet makeup. Table 7.2 shows VMT to generally follow vehicle ownership. Some small deviations exist between a given powertrain type's fleet composition and VMT composition. The can be explained by variations in average vehicle age between powertrains (with newer vehicles accumulating more VMT than older ones), differences in total household VMT, and differences in vehicle ownership, which dictates how many vehicles a household's total VMT will be distributed between.

Table 7.2: U.S. VMT without Availability of AVs and SAVs

		SAVs		Privately-Held Vehicles						
Year	*US VMT*	*% DRS*	*% Private SAV*	*% AV*	*% HV*	*% Diesel*	*% Gasoline*	*% HEV*	*% PHEV*	*% BEV*
2017	1,019 B	n/a	n/a	n/a	100%	2.1%	94.4%	2.8%	0.2%	0.3%
2020	948.5 B	n/a	n/a	n/a	100%	2.2%	75.5%	11.6%	8.6%	2.0%
2025	897.0 B	n/a	n/a	n/a	100%	2.9%	46.0%	24.6%	22.8%	3.7%
2030	876.7 B	n/a	n/a	n/a	100%	2.3%	23.8%	34.3%	34.2%	5.3%
2035	880.1 B	n/a	n/a	n/a	100%	2.5%	12.3%	38.8%	40.7%	5.7%
2040	841.9 B	n/a	n/a	n/a	100%	2.9%	6.4%	40.3%	44.0%	6.4%
2045	833.4 B	n/a	n/a	n/a	100%	2.4%	6.9%	40.7%	43.6%	6.3%
2050	856.3 B	n/a	n/a	n/a	100%	2.3%	6.8%	41.2%	44.1%	5.6%

7.1.2 5% Annual AV Premium Decline, with HV Capability

Table 7.3: U.S. Privately-Owned Fleet Composition with 5% AV Premium Decline & HV Capability

Year	Vehicles	% AV	% HV	% Diesel	% Gasoline	% HEV	% PHEV	%BEV
2017	222.1 M	0%	100%	1.9%	95.1%	2.5%	0.2%	0.4%
2020	212.6 M	0%	100%	2.4%	75.3%	11.7%	9.0%	1.6%
2025	223.7 M	0%	100%	2.6%	46.8%	24.4%	22.8%	3.4%
2030	225.1 M	0.9%	99.1%	2.4%	26.5%	34.1%	32.6%	4.6%
2035	242.9 M	8.6%	91.4%	2.2%	13.7%	40.2%	39.3%	4.8%
2040	252.4 M	22.1%	77.9%	2.3%	7.1%	43.0%	42.5%	5.1%
2045	255.1 M	38.1%	61.9%	1.9%	6.2%	43.3%	43.7%	5.0%
2050	253.4 M	55.1%	44.9%	1.9%	6.4%	43.8%	42.3%	5.5%

Under the scenario of a constant, 5-percent annual decline in an AV's purchase price premium, where HV capability is maintained in all fully-autonomous vehicles, Table 7.3 shows that total vehicle ownership increases until year 2045, though the rate slows in the 2030s, before a slight decline after year 2045. Vehicle ownership reaches roughly 14% higher than in 2017. AV ownership picks up slowly, but begins increasing dramatically after year 2035, to reach over half of private vehicle ownership by year 2050. While battery-electric vehicle ownership rises to only 5.5% of all vehicles owned in 2050, hybrid-electric and plug-in hybrid vehicles experience a much more significant increase, rising to 43.8% and 42.3% of vehicle ownership in 2050, respectively, as gasoline ownership drops precipitously to 6.4% in year 2050. Interestingly, diesel vehicle ownership rises slightly in early years, before declining back to current ownership levels by 2050. This five-percent annual price decline from an initial value of $20,000 results in an AV price premium of $3,680.52 in year 2050.

Table 7.4: U.S. VMT with 5% AV Premium Decline & HV Capability

		SAVs		Privately-Held Vehicles						
Year	*US VMT*	*% DRS*	*% Private SAV*	*% AV**	*% HV*	*% Diesel*	*% Gasoline*	*% HEV*	*% PHEV*	*%BEV*
2017	1,019 B	0.0%	0.0%	0.0%	99.9%	2.1%	94.4%	2.8%	0.2%	0.3%
2020	958.4 B	2.5%	4.7%	0.0%	92.8%	2.3%	70.3%	10.8%	8.1%	1.2%
2025	899.1 B	3.4%	6.8%	0.0%	90.1%	2.3%	41.8%	21.6%	21.3%	3.0%
2030	886.7 B	4.4%	8.5%	1.4%	85.6%	2.1%	21.2%	30.0%	29.6%	4.1%
2035	900.6 B	5.6%	11.0%	9.6%	73.8%	1.8%	10.2%	33.4%	33.9%	4.0%
2040	924.3 B	7.2%	14.0%	20.6%	58.2%	1.8%	5.2%	33.3%	34.8%	3.6%
2045	939.9 B	9.2%	18.0%	32.0%	40.8%	1.3%	4.3%	30.6%	32.8%	3.8%
2050	948.6 B	12.1%	23.3%	39.8%	24.9%	1.2%	4.1%	20.8%	27.6%	3.6%

* %AV denotes VMT by AV-capable vehicles, some of which may be in HV mode.

Table 7.4 shows VMT by powertrain type to roughly follow vehicle ownership, though powertrain types with rising market share experience proportionally higher VMT than those with falling market share, since newer vehicles tend to experience more VMT than older vehicles. Once SAVs become available, their use grows gradually until overall use comprises 35.4% of total VMT in year 2050, with private SAV mileage generally accounting for about double the DRS mileage. VMT by private AVs rises disproportionally quickly, compared to VMT by HVs, likely owing to the average AV being newer than the average HV as AVs continue to gain market share. Overall VMT experiences an initial decline, then a slight gradual increase as SAV use increases, giving zero vehicle households the opportunity to accumulate automobile travel via SAVs.

In this and other scenarios where privately-owned AVs are allowed to retain human-driving capability, the column for percent VMT by privately-held AVs displays the percent of VMT by AV-capable vehicles. VMT in AV mode may be only a portion of this amount, since owners may opt for human-driving some of the time. Survey results from Part 1 of this thesis indicate that the average respondent would use AV mode for 36% of their VMT in a vehicle capable of both. However, it stands to reason that such vehicles may be in AV mode for a higher percentage of their VMT, since those who intend to travel in AV mode would be expected to be more likely to acquire an AV-capable vehicle than those who would use the AV mode less. Those who purchase AV-capable vehicles in early years may be people who are enthusiastic about using the AV mode, and over time, people's attitudes towards driving may change, resulting in a higher willingness to use the AV mode more frequently. It is possible, however, that total VMT in AV mode may be lower in these scenarios than in the scenarios in which AVs are not allowed to retain a human-driving option.

7.1.3 5% Annual AV Premium Decline, without HV Capability

Table 7.5: U.S. Privately-Owned Fleet Composition with 5% AV Premium Decline & No HV Capability

Year	Vehicles	% AV	% HV	% Diesel	% Gasoline	% HEV	% PHEV	%BEV
2017	222.1 M	0.0%	100.0%	1.9%	95.1%	2.5%	0.2%	0.4%
2020	218.6 M	0.0%	100.0%	2.1%	75.2%	11.2%	9.9%	1.7%
2025	227.6 M	0.0%	100.0%	2.3%	47.6%	24.2%	22.4%	3.5%
2030	238.9 M	0.1%	99.9%	2.1%	26.1%	34.9%	31.9%	5.0%
2035	257.3 M	2.4%	97.6%	2.2%	12.7%	41.4%	37.9%	5.8%
2040	261.1 M	8.7%	91.3%	2.2%	6.4%	45.4%	40.0%	6.1%
2045	258.2 M	19.5%	80.5%	2.1%	6.5%	45.3%	40.0%	6.2%
2050	253.3 M	32.4%	67.6%	2.1%	6.4%	45.4%	40.2%	5.8%

As Table 7.5 shows, in the scenario where the AV technology premium drops by five percent annually, but where a human-driven option is not available in AVs, total vehicle ownership and vehicle ownership by powertrain follow fairly similar numbers to the previous scenario. Ownership of plug-in hybrid powertrains remains slightly lower, while battery-electric and hybrid ownership experience a slightly higher increase than in the previous scenario. The notable difference is that AV ownership remains much lower, rising to a level in 2050 that is less than one third of privately-owned vehicles and, over 20 precentage points lower than the corresponding scenario that retains HV capabilities in AVs, due to the lower WTP for AVs when they lack an option for human driving.

Table 7.6: U.S. VMT with 5% AV Premium Decline & no HV Capability

		SAVs		Privately-Held Vehicles						
Year	*US VMT*	*% DRS*	*% Private SAV*	*% AV*	*% HV*	*% Diesel*	*% Gasoline*	*% HEV*	*% PHEV*	*%BEV*
2017	1,019 B	0.0%	0.0%	0.0%	99.9%	2.1%	94.4%	2.8%	0.2%	0.3%
2020	966.6 B	2.5%	4.7%	0.0%	92.7%	2.1%	71.0%	10.0%	8.4%	1.3%
2025	918.6 B	3.3%	6.4%	0.0%	90.2%	2.2%	42.3%	22.0%	20.8%	2.8%
2030	894.2 B	4.3%	8.5%	0.2%	87.0%	1.8%	20.7%	31.2%	29.3%	4.2%
2035	897.6 B	5.6%	11.0%	3.3%	80.2%	1.9%	9.4%	35.1%	32.5%	4.4%
2040	914.2 B	7.2%	14.1%	10.3%	68.3%	1.9%	4.9%	34.7%	32.3%	4.8%
2045	934.6 B	9.3%	18.1%	18.5%	54.2%	1.6%	4.4%	31.8%	30.4%	4.5%
2050	946.2 B	12.1%	23.3%	25.1%	39.4%	1.4%	3.7%	28.7%	27.1%	3.6%

Table 7.6 shows that VMT by privately-held AVs remains lower than in the previous scenario, due to their lower adoption rates. Other VMT numbers remain in similar ranges as the previous scenario. Overall VMT is slightly lower than in the previous scenario.

7.1.4 7.5% Annual AV Premium Decline, with HV Capability

Table 7.7: U.S. Privately-Owned Fleet Composition with 7.5% AV Premium Decline & HV Capability

Year	Vehicles	% AV	% HV	% Diesel	% Gasoline	% HEV	% PHEV	%BEV
2017	222.1 M	0.0%	100.0%	1.9%	95.1%	2.5%	0.2%	0.4%
2020	225.3 M	0.0%	100.0%	2.0%	73.8%	12.8%	2.0%	1.4%
2025	235.6 M	0.1%	99.9%	1.9%	45.0%	26.8%	1.9%	3.1%
2030	244.0 M	3.8%	96.2%	1.5%	24.7%	37.3%	2.6%	4.2%
2035	251.1 M	17.4%	82.6%	1.5%	12.9%	42.6%	8.1%	5.3%
2040	259.3 M	36.7%	63.3%	1.8%	6.5%	45.6%	15.7%	5.5%
2045	258.9 M	56.9%	43.1%	2.1%	6.8%	45.3%	23.4%	5.1%
2050	258.1 M	73.7%	26.3%	2.3%	7.0%	45.3%	29.9%	5.4%

Declines in the AV technology premium can significantly accelerate adoption of the technology. Table 7.6 shows that, under the WTP scenario that includes maintaining a human driving option, a 7.5 percent annual reduction in the AV technology premium results in AVs comprising 73.7% of the U.S. private vehicle fleet by 2050, nearly 20 percentage points higher than the AV share with only a five percent decline. Interestingly, adoption of plug-in hybrid vehicles grows much more slowly than it does with a 5% annual AV technology premium reduction. This more aggressive 7.5 percent annual drop means AV technology premiums decline from $20,000 at the start of the simulation, to $1,526.54 in 2050.

Table 7.8: U.S. VMT with 7.5% Technology Premium Decline & HV Capability

		SAVs		Privately-Held Vehicles						
Year	*US VMT*	*% DRS*	*% Private SAV*	*% AV*	*% HV*	*% Diesel*	*% Gasoline*	*% HEV*	*% PHEV*	*% BEV*
2017	1,019 B	0.0%	0.0%	0.0%	99.9%	2.1%	94.4%	2.8%	0.2%	0.3%
2020	970.8 B	2.4%	4.6%	0.0%	92.9%	1.9%	70.3%	10.8%	8.8%	1.2%
2025	907.2 B	3.3%	6.4%	0.1%	90.1%	1.9%	40.0%	23.7%	21.9%	2.7%
2030	901.8 B	4.3%	8.4%	4.0%	83.3%	1.4%	20.7%	32.4%	29.3%	3.6%
2035	900.1 B	5.6%	11.0%	17.7%	65.7%	1.4%	10.5%	35.1%	32.3%	4.1%
2040	920.6 B	7.2%	14.1%	34.9%	43.8%	1.7%	5.0%	35.7%	32.3%	4.1%
2045	938.2 B	9.3%	18.0%	46.9%	25.8%	1.6%	4.9%	32.8%	29.8%	3.7%
2050	948.4 B	12.1%	23.2%	50.1%	13.6%	1.6%	4.5%	28.6%	26.5%	3.5%

***** %AV denotes VMT by AV-capable vehicles, some of which may be in HV mode.

VMT among privately-held vehicles largely reflects vehicle ownership in this scenario, according to Table 7.8. It is notable that by 2050, 86.4% of all VMT is expected to be in vehicles capable of self-driving; 50.1% through private vehicles, and 35.3% through SAVs. The VMT among private vehicles is again disproportionately distributed among AVs, compared to HVs.

7.1.5 7.5% Annual AV Premium Decline, without HV Capability

Table 7.9: U.S. Privately-Owned Fleet Composition with 7.5% AV Premium Decline & no HV Capability

Year	Vehicles	% AV	% HV	% Diesel	% Gasoline	% HEV	% PHEV	%BEV
2017	222.1 M	0.0%	100.0%	1.9%	95.1%	2.5%	0.2%	0.4%
2020	222.2 M	0.0%	100.0%	1.8%	74.1%	13.0%	9.3%	1.8%
2025	229.5 M	0.0%	100.0%	2.2%	46.6%	26.0%	22.3%	3.0%
2030	235.1 M	1.8%	98.2%	2.0%	27.4%	34.7%	31.6%	4.2%
2035	239.9 M	11.0%	89.0%	1.8%	13.2%	40.9%	38.6%	5.5%
2040	247.6 M	23.9%	76.1%	2.0%	7.1%	43.3%	42.0%	5.5%
2045	250.3 M	39.3%	60.7%	1.8%	6.6%	44.4%	41.6%	5.6%
2050	251.3 M	52.5%	47.5%	2.0%	5.9%	45.2%	41.1%	5.8%

Without retaining a human driving option in AVs, Table 7.9 shows that their adoption remains slower than if the option is maintained with a 7.5 percent annual AV technology premium decline, and interestingly, adoption rates are lower than with a five percent annual AV price premium decline and HV capabilities retained, though AVs still comprise over half of private vehicle ownership by year 2050. Total vehicle ownership rises to lower levels under this scenario than it does if HV capability is retained.

Table 7.10: U.S. VMT with 7.5% AV Premium Decline & no HV Capability

		SAVs		Privately-Held Vehicles						
Year	*US VMT*	*% DRS*	*% Private SAV*	*% AV*	*% HV*	*% Diesel*	*% Gasoline*	*% HEV*	*% PHEV*	*%BEV*
2017	1,019 B	0.0%	0.0%	0.0%	99.9%	2.1%	94.4%	2.8%	0.2%	0.3%
2020	966.5 B	2.5%	4.7%	0.0%	92.8%	1.8%	70.1%	11.5%	8.2%	1.3%
2025	906.0 B	3.4%	6.8%	0.0%	90.1%	2.0%	41.1%	23.7%	20.8%	2.6%
2030	889.7 B	4.4%	8.5%	2.3%	84.8%	1.9%	22.7%	30.1%	28.6%	3.8%
2035	887.0 B	5.8%	11.2%	12.1%	71.0%	1.7%	10.3%	33.3%	33.6%	4.2%
2040	900.7 B	7.5%	14.4%	24.7%	53.4%	1.9%	5.2%	32.7%	34.3%	4.1%
2045	911.2 B	9.6%	18.6%	33.7%	38.1%	1.2%	4.7%	31.3%	31.2%	3.3%
2050	928.5 B	12.5%	23.8%	39.3%	24.3%	1.4%	4.1%	28.2%	26.7%	3.4%

Table 7.10 shows that changes in VMT by vehicle type largely mirror changes in vehicle ownership. As with other scenarios, the ratio of VMT between AVs and HVs is higher than the ratio for vehicle ownership. Again, age of the vehicles is likely the main factor, though it is also possible that households of higher VMT may tend to acquire AVs at different rates than the population as a whole. Distance to the city center may be a reasonable proxy for VMT, and interestingly enough, this explanatory variable has a negative relationship with WTP for AV technology if HV capability is not maintained (no statistically significant relationship exists for WTP with HV capability). Another explanation may be that households with fewer vehicles are more likely to acquire an AV, in which case the household's VMT is distributed amongst fewer vehicles, resulting in higher VMT for each individual vehicle. The regression models for WTP support this, showing a negative relationship between the number of vehicles in the household and WTP for AV technology for both with and without the option to maintain HV capability.

7.1.6 10% Annual AV Premium Decline, with HV Capability

Table 7.11: U.S. Privately-Owned Fleet Composition with 10% AV Premium Decline & HV Capability

Year	Vehicles	% AV	% HV	% Diesel	% Gasoline	% HEV	% PHEV	%BEV
2017	222.1 M	0.0%	100.0%	1.9%	95.1%	2.5%	0.2%	0.4%
2020	221.2 M	0.0%	100.0%	1.7%	74.9%	11.0%	10.8%	1.6%
2025	225.8 M	0.5%	99.5%	2.0%	48.7%	22.5%	23.9%	2.8%
2030	239.2 M	12.5%	87.5%	2.2%	27.7%	31.7%	33.9%	4.5%
2035	253.3 M	33.2%	66.8%	1.9%	13.3%	38.8%	40.4%	5.5%
2040	253.4 M	53.6%	46.4%	1.9%	7.4%	42.1%	43.6%	5.0%
2045	258.0 M	71.3%	28.7%	1.8%	7.0%	43.2%	43.2%	4.9%
2050	261.1 M	84.3%	15.7%	1.9%	7.2%	43.4%	42.4%	5.1%

If HV capability is maintained in AVs, a 10% annual technology premium decline results in rapid adoption of AVs after year 2025, with them comprising 84.3% of the U.S. private vehicle fleet in year 2050, according to Table 7.11. A 10-percent annual AV premium drop means that the premium drops from $20,000 in 2026 to only $618 in 2050. This is a very aggressive price decline, for which significant advances in producing the necessary technology, especially LIDAR, at lower cost would be necessary in order to realize. It is possible that such a rapid decline cannot feasibly be sustained to reach such a low value by 2050, though adoption of some safety and connectivity technology as a potential requirement in human-driven vehiicles may increase their cost, thus lowering the premium for AVs.

Table 7.12: U.S. VMT with 10% AV Premium Decline & HV Capability

		SAVs		Privately-Held Vehicles						
Year	*US VMT*	*% DRS*	*% Private SAV*	*% AV*	*% HV*	*% Diesel*	*% Gasoline*	*% HEV*	*% PHEV*	*%BEV*
2017	1,019 B	0.0%	0.0%	0.0%	99.9%	2.1%	94.4%	2.8%	0.2%	0.3%
2020	963.2 B	2.5%	4.7%	0.0%	92.8%	1.9%	69.7%	10.4%	9.4%	1.3%
2025	917.1 B	3.3%	6.4%	0.7%	89.6%	1.9%	42.7%	21.4%	22.0%	2.3%
2030	913.5 B	4.2%	8.3%	12.6%	74.9%	2.1%	22.8%	28.9%	29.8%	3.9%
2035	912.9 B	5.5%	10.8%	31.5%	52.2%	1.7%	10.0%	33.4%	34.0%	4.6%
2040	911.5 B	7.3%	14.2%	47.1%	31.4%	1.3%	5.2%	33.6%	34.4%	4.0%
2045	931.4 B	9.4%	18.2%	55.7%	16.7%	1.3%	4.6%	31.0%	32.1%	3.4%
2050	957.9 B	12.0%	23.1%	57.3%	7.7%	1.1%	4.6%	27.1%	29.1%	3.1%

* %AV denotes VMT by AV-capable vehicles, some of which may be in HV mode. As with the other scenarios, Table 7.12 shows that VMT generally follows vehicle ownership, but with a disproportionate shift away from HV miles towards AV miles. In this very favorable scenario, 92.3% of all VMT is via self-driving capable vehicles in year 2050

7.1.7 10% Annual AV Premium Decline, without HV Capability

Table 7.13: U.S. Privately-Owned Fleet Composition with 10% AV Premium Decline & no HV Capability

Year	Vehicles	% AV	% HV	% Diesel	% Gasoline	% HEV	% PHEV	%BEV
2017	222.1 M	0.0%	100.0%	1.9%	95.1%	2.5%	0.2%	0.4%
2020	219.5 M	0.0%	100.0%	2.0%	74.7%	12.2%	9.8%	1.4%
2025	231.4 M	0.3%	99.7%	2.0%	47.2%	25.3%	22.9%	2.7%
2030	238.6 M	5.8%	94.2%	1.7%	25.4%	34.4%	34.6%	3.9%
2035	248.6 M	18.8%	81.2%	1.9%	12.8%	41.4%	39.0%	5.0%
2040	247.7 M	35.7%	64.3%	1.7%	7.0%	44.6%	41.1%	5.7%
2045	251.0 M	52.6%	47.4%	2.0%	7.3%	44.0%	40.6%	6.1%
2050	259.4 M	65.2%	34.8%	2.3%	7.6%	42.8%	41.5%	5.8%

Table 7.13 shows that the scenario including a 10-percent annual decline in the AV technology premium, and where human-driving capabilities are not maintained in AVs, results in AV ownership in year 2050 that is 19.1 percentage points lower than for the same price decline with the option of maintaining human-driving capabilities. AV adoption in this scenario is lower than that in the scenario of only a 7.5 percent AV price premium decline when the human-driven option is retained in AVs. Table 7.14 shows the VMT by mode and vehicle type for this scenario.

Table 7.14: U.S. VMT with 10% Technology Premium Decline & no HV Capability

		SAVs		Privately-Held Vehicles						
Year	*US VMT*	*% DRS*	*% Private SAV*	*% AV*	*% HV*	*% Diesel*	*% Gasoline*	*% HEV*	*% PHEV*	*%BEV*
2017	1,019 B	0.0%	0.0%	0.0%	99.9%	2.1%	94.4%	2.8%	0.2%	0.3%
2020	958.5 B	2.5%	4.7%	0.0%	92.8%	2.0%	70.7%	10.9%	8.2%	1.0%
2025	913.2 B	3.3%	6.4%	0.3%	89.9%	2.3%	42.6%	22.4%	20.7%	2.4%
2030	902.3 B	4.3%	8.4%	6.6%	80.7%	2.0%	20.4%	30.1%	31.2%	3.6%
2035	909.5 B	5.6%	10.9%	19.8%	63.8%	1.7%	9.8%	34.8%	33.4%	3.8%
2040	912.1 B	7.3%	14.2%	34.3%	44.1%	1.2%	5.4%	34.7%	33.1%	4.0%
2045	933.9 B	9.3%	18.1%	44.0%	28.6%	1.2%	5.3%	32.2%	29.8%	4.1%
2050	956.5 B	12.0%	23.1%	47.1%	17.9%	1.4%	4.9%	27.5%	28.0%	3.2%

7.2 HOME LOCATION

Table 7.15: Average Household Distance to City Center (in miles) for Each Scenario

		With HV Option			Without HV Option		
Year	*BAU*	*5% Drop*	*7.5% Drop*	*10% Drop*	*5% Drop*	*7.5% Drop*	*10% Drop*
2017	*10.005 mi*	10.005	10.005	10.005	10.005	10.005	10.005
2020	*9.996*	10.022	10.011	10.008	10.013	10.010	10.026
2025	*10.013*	10.027	10.022	10.014	10.016	10.018	10.033
2030	*10.027*	10.021	10.025	10.014	10.018	10.018	10.042
2035	*10.027*	10.027	10.028	10.014	10.022	10.026	10.048
2040	*10.025*	10.026	10.028	10.014	10.022	10.031	10.049
2045	*10.033*	10.026	10.028	10.017	10.022	10.031	10.052
2050	*10.031*	10.026	10.028	10.017	10.017	10.036	10.040

Note: % Drop refers to annual decline in AV technology premium

While the survey respondents indicated that respondents may be influenced by the availability of AVs and SAVs to move closer to the city center than they otherwise would, they also indicated an overall initial preference for moving farther from the city center. Table 7.15 shows that the simulation results indicate an overall movement away from the city center. Average increase in home distance from the city center by 2050 ranges from 0.12% to 0.35%. Overall, this is a mild shift away from the city center, but may suggest a continued popularity of suburban an exurban living after AVs and SAVs become available to the public. The rise in average distance from the city center slows significantly for all scenarios once SAVs become available. The business as usual scenario results in average household distance in 2050 that is similar to that of the other scenarios, though it reaches that value more gradually. Overall, differences in home location between the scenarios are small.

Chapter 8: Conclusions for Part Two

The availability of an option to retain human-driving capabilities in AVs has a noticeable effect on their level of adoption and their share of total VMT, due to the higher WTP that exists for AVs if they include that human-driven option. This presents a potential dilemma for policy-makers and AV manufacturers. The potential, safety, congestion, and emissions impacts may make it advantageous to accelerate adoption of AVs as quickly as possible if those effects are determined to provide an overall benefit. However, if a large number of AVs are equipped with the capability for human-driving, a significant amount of VMT in AVs may actually be human-driven, negating a portion of the benefits of shifting the United States fleet toward AVs. The average respondent in the indicated an intention to use AV mode for only 35.9% of travel miles in a vehicle that is capable of both human- and self-driving modes, which would result in a lower percentage of VMT in autonomous mode if the human-driven option is retained for AVs, regardless of the price premium scenario. Reasons exist to doubt that self-driving travel would actually be this low in vehicles capable of both modes. First, this a hypothetical question asked of respondents who have no familiarity with self-driving vehicles, and likely very little understanding of what situations they would actually choose self- or human-driving modes. Further, the question was asked of all respondents, including those who have little to no interest in AVs. These people are less likely to acquire an AV, especially in early years availability, so those who actually do acquire AVs are likely more enthusiastic about the self-driving mode and possibly more likely to use it for a larger percentage of their travel in an AV.

BEV ownership remains comparatively low throughout the simulation, so government policies to incentivize their adoption (such as tax credits, low-cost charging rates per kWh, reduced road tolls, and/or special parking spaces), or a significant technological breakthrough, may be necessary to increase their adoption and use rates. However, HEV and PHEV ownership and use are predicted to grow to dominate the private vehicle fleet. This suggests a future with more efficient fuel consumption and lower emissions, but one which is still largely dependent on internal combustion engines, especially for longer trips, unless further intervention or breakthoughs occur.

The home location portion of the simulation shows a slight shift away from the city center, which slows upon the availability of AVs and SAVs to the public. This suggests a minimal impact of AVs and SAVs on home location choice. Perhaps a reduced need for parking space will allow for more infill development in urban areas, providing people ample opportunities to live and work in more compact urban areas. The results here are dependent on stated preference survey results, asking respondents how transportation technology which they are not familiar with may impact a future home location movement. This unfamiliarity may make it difficult for respondents to have a good sense of how their decisions would be affected. For this reason, further study should be conducted on the effects of AVs and SAVs on home location choice, as well as reactions to the technologies in general, since any study at this stage relies on stated preference data.

The way human aging is modeled is a limitation on the results presented here. The current U.S. population is unevenly distributed by age, with certain age groups having a larger population than others. The aging model used here effectively shifts each bulge or valley in the current population distribution forward (eventually rolling back to age 18 after the aribitrary cutoff age of 80 [in the category where all over-age-65 respondents' households were placed]). This results in changing age demographics in every year of the simulation, but does not necessarily represent how these demographics will actually change in the future. Complex factors, including birth rate, age distribution of deaths, and immigration rates, will affect the population's age distribution in inknown ways. For this reason, the age distribution created by this model may be a source of error for the results of this study. To get a sense for this, one of the scenarios was run with a constant age distribution and no aging (which itself is not necessarily an accurate representation of future demographics). Holding age constant results in slower growth of private vehicle ownership, but a higher proportion of privately-owned vehicles being self-driving (11.5 percentage points in 2050). Constant age also results in higher proportions of privately-owned vehicles being gasoline-powered, plug-in hybrid, and battery-electric, at the expense of diesel-powered and hybrid-electric vehicles. While the total VMT follows a similar pattern as it does with aging, keeping age constant results in more SAV use, rising to a total of all VMT that is roughly ten percentage points higher than with aging, while privately-held vehicle VMT favors AV miles more when age is constant. Holding age constant also results in migration somewhat farther away from the city center, with average distance to the city center in 2050 being 10.352 miles, a greater than one percent increase, which is much higher than any scenario with the original aging pattern. While this suggests that age distribution and household evolution can produce noticeable effects on simulation results, it is impossible to know how the age distribution of the United States population will change over time. The results of this study serve as one estimate of the evolution of the U.S. passenger-vehicle fleet and Americans' ground-based travel patterns, the accuracy of which will be influenced by a number of changing factors, including population age distribution, technological innovations, manufacturer and fleet-operator pricing decisions, and social network effects.

PART 3: COSTS AND BENEFITS OF ELECTRIFYING AND AUTOMATING U.S. BUS FLEETS

Chapter 9: Introduction and Motivation for Part Three

Transportation is on the cusp of technological shifts. Fully autonomous technology is moving closer to reality, and alternative power sources are experiencing technological advancement that is pushing them to challenge the status quo. U.S. travel is dominated by personal automobiles, with limited use of all other modes. Automobile dependence has resulted in sprawling development, significant traffic congestion, and limited public transportation options. Like many American cities, especially those in the south, Austin, Texas offers few rail travel options, with public transit occurring primarily via bus. Austin's public transportation is managed by Capital Metro. Reliance on diesel-powered transit buses for most of Austin's public transportation adds to the emissions produced on the region's roadways and limits Capital Metro's ability to broadly serve Austin's population. As a result, emerging technologies to reduce emissions and costs, and/or to attract more travelers to improved transit services should be considered.

9.1 Scope and Purpose

This paper analyzes the life-cycle cost implications of bus fleet electrification and automation, using Austin's Capital Metro as a case study. Based on several likely cost assumption scenarios, adoption schedules are developed and evaluated.

9.2 Power Sources

Diesel power currently dominates transit buses, including Capital Metro's fleet. Finite fossil fuel reserves and increasing global demand present uncertainties around the long-term availability of diesel and natural gas as fueling options. Additionally, climate change concerns and local emissions makes diesel power less attractive than alternatives in most settings. Furthermore, many travelers may dislike the noise and local air pollution (and engine and air conditioning heat released) while waiting for, boarding and alighting diesel buses. For such reasons, it is useful for transit agencies to explore non-petroleum power options.

Natural gas is gaining popularity as replacement for diesel in medium to heavy duty vehicles, but its benefits are limited. Tan et al. (2015) show liquified natural gas (LNG) to increase GHG emissions, and compressed natural gas (CNG) to offer at most a 2% reduction in emissions. Biofuels present an alternative bus fuel option with minimum apparent equipment and infrastructure disruption. However, since biofuels are burned similarly to diesel in a bus engine and emitted via tailpipe, many of the negatives of diesel power remain with biofuel-powered buses.

Hydrogen fuel cell buses have been used in pilot programs at transit agencies across the United States (Eudy et al., 2016). However, Lajunen and Lipman (2016) point out that the source of the hydrogen determines the total emissions generated from fuel cell vehicles. An economical or energy-efficient way of producing hydrogen from non-fossil fuel sources has not been developed, so 95% of hydrogen produced in the United States is made from methane (Eco Global Fuels, 2012), the production of which creates carbon dioxide (a greenhouse gas) as a byproduct. Tan et al. (2015) show hydrogen fuel cell-powered buses to increase emissions, compared to diesel power, when the hydrogen is produced from natural gas. Combined with a lack of existing delivery infrastructure for hydrogen fuel, this presents significant obstacles to the widespread adoption of hydrogen as a fuel source in most locations. Mechanical energy storage methods, such as flywheels or compressed air, have also shown potential for useful energy storage, but these technologies are not currently available as a primary power source.

Battery-electric power is another alternative, which can be free of fossil fuels if electricity generation comes from renewable sources (like hydroelectric power, sun and/or wind). Even when powered by non-renewable natural gas electricity generation, Tan et al. (2015) find battery-electric transit buses to reduce emissions by 31% compared to petroleum-fueled buses. Electric vehicles are already in use, as both personal automobiles and transit buses, and this technology (and its costs) continue to improve (Nykvist & Nilsson, 2015). Hybrid-electric buses allow some use of recovered electric power, but rely largely on diesel fuel, with its attendant issues (Lajunen and Lipman, 2016). For the foreseeable future, battery-electric buses appear most promising and so are the focus of the power-source portions of this report.

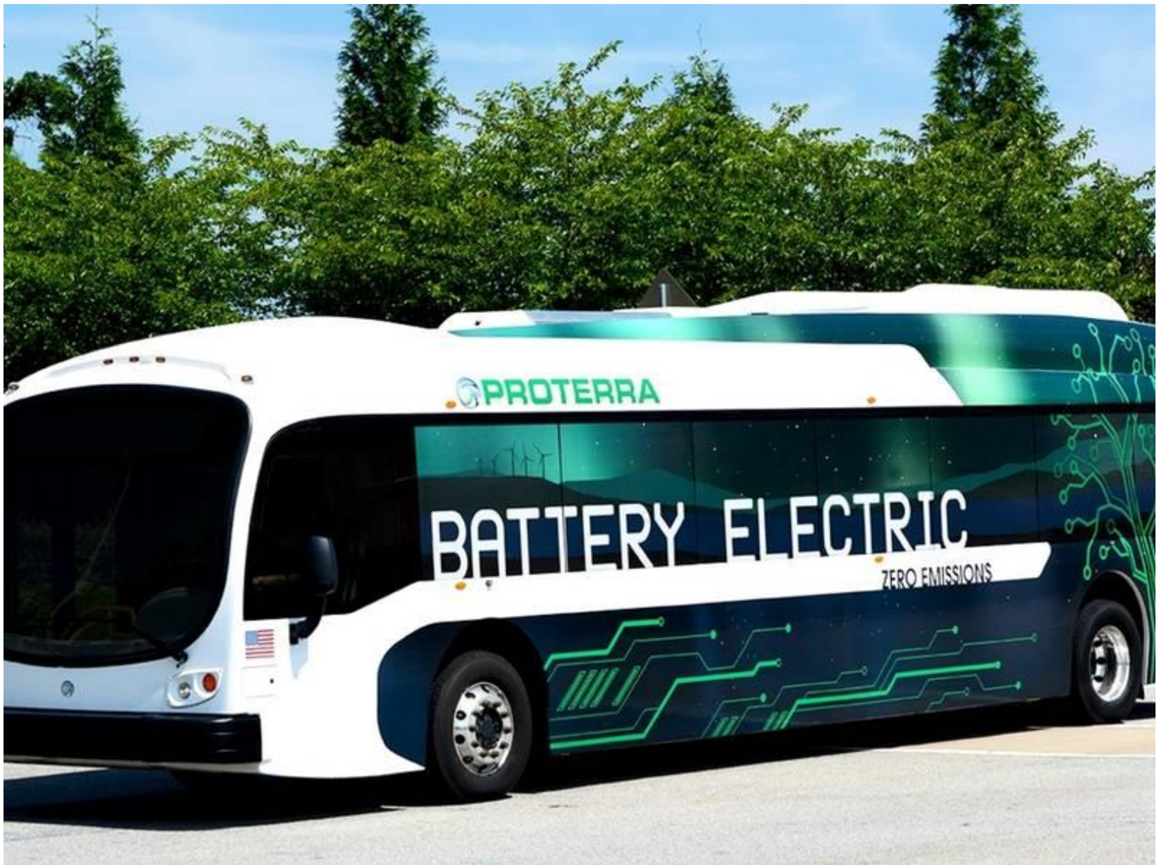

Figure 9.1: A Proterra Battery-Electric Bus (Loose, 2017)

9.3 Autonomous Technology

Tremendous advances are being made in the field of autonomous vehicle (AV) technology. Fully autonomous driving is expected to produce improvements in safety, roadway capacity, fuel consumption, and emissions (Fagnant and Kockelman, 2014, Fagnant and Kockelman, 2015). Though much of the focus has been on personal use of autonomous technology, public transit stands to be affected significantly, especially bus service, where lower vehicle capacities compared to rail modes currently result in higher per-passenger driver costs. Various levels of automation exist, but this report focuses on fully autonomous buses, which can operate without a human driver. Speculation on how the introduction of fully autonomous vehicles will impact public transit varies among experts. Predictions range from a belief that shared AV fleets of personal-sized vehicles will effectively replace public transit, to a possibility of fleets of smaller autonomous buses, to an expectation that public transit will be strengthened by autonomous technology (Freemark, 2015). Eliminating or reducing mass public transit would be problematic, since replacing bus trips with personal vehicle trips would inevitably increase vehicle miles traveled, and therefore, congestion. Additionally, shared AVs may prove to be too expensive for many current bus users. With smaller fully autonomous buses, more vehicles would be needed to maintain current capacity. While this could be used to improve frequency, it may result in headways too close to maintain on some routes, and will limit the ability of the routes to cope with any added demand. Additionally, a shift to more vehicles with lower occupancy could contribute to worsening congestion. Full size transit buses alleviate some of the concerns associated with smaller vehicles, by maintaining current capacity without a need to add vehicles. In fact, since the human driver could be removed, it may be possible to make more capacity available for passengers. For these reasons, as well as ease of comparison, the autonomous technology portions of this report focus on the use of fully autonomous technology in full-size transit buses.

9.4 Current Availability and Co-Adoption

Electric vehicle technology is currently available, with multiple auto manufacturers selling fully electric models. High-level autonomous technology is likely still a few years away from widespread availability, though fully autonomous cars (Davies, 2016) and small buses (Ayre, 2016) have begun carrying passengers in public testing scenarios. However, both may become commonplace in the future for public transportation. It is possible that both technologies will be adopted simultaneously by many transit agencies. For this reason, both technologies are analyzed individually in this report, as well as the possibility of simultaneous adoption.

Chapter 10: Implementation Costs and Impacts

This section analyzes and discusses the costs of implementing each technology individually, including the potential for cost savings. Additionally, qualitative effects are discussed. Finally, co-implementation of both technologies is discussed.

10.1 Electric Buses

This section shows cost estimates for battery-electric buses relative to diesel buses. Estimates of the purchase price of electric buses vary, so a recent actual purchase price of electric buses is used for calculations and estimations. According to Brianna Gurciullo (2016), the battery-electric buses purchased in 2016 by the Chicago Transit Authority (CTA) carried a purchase price of $800,000 each, while Christopher MacKechnie (2016) lists the typical purchase price of a diesel transit bus at $300,000. This means the current delta for a battery-electric bus is about $500,000 above the cost of a diesel bus. Capital Metro’s recent diesel purchases cost about $450,000 each, due to additional equipment and electronics capabilities that are added to their vehicles that would mostly be expected to be included in electric buses due to their more electronically-dependent nature (Borowski, 2017), which leaves a $350,000 delta in the purchase price between diesel and battery-electric buses for this transit agency. Analysis in this report is performed considering both a $300,000 purchase price for diesel buses and a $450,000 diesel purchase price. U.S. transit agencies may apply for Federal Transit Administration grants to help cover the additional capital costs, and other countries may have similar programs; but these funds are limited, so this analysis does not assume any additional assistance.

Table 10.1: Costs of Diesel and Electric Buses at 2016 Prices

Costs of Diesel and Electric buses at $300K and $450K Diesel Purchase Prices			
	Purchase Price	Annual Fuel Expense	12-Year Life-cycle Cost
Diesel ($300K)	$300,000	$38,592	$763,107
Diesel ($450K)	$450,000	$38,592	$913,107
Electric	$800,000	$13,592	$963,107
Difference ($300K)	*$500,000*	*($25,000)*	*$200,000*
Difference ($450K)	*$350,000*	*($25,000)*	*$50,000*

The largest opportunity for cost savings with electric vehicles is from fuel costs. Capital Metro's (2016b) bus fleet consists of 438 vehicles with a 2017 budget showing annual diesel-bus fuel costs of $16.90 million (Capital Metro, 2016a), or $38,592 per bus. Gurciullo (2016) estimates net annual fuel savings of $25,000 per electric bus, or $300,000 over a12-year life of the bus, which Eudy (2016) notes as a typical transit bus lifespan. This alone is not enough to recoup the current premium for electric propulsion, leaving an added life-cycle cost of $200,000 (per bus) if diesel bus purchase prices are $300,000, or $50,000 if diesel buses cost $450,000 each. In total, this would increase Capital Metro's annual budget by $7.3 million or $1.835 million, respectively, if every new bus were electric and purchased at current prices. The agency's operating budget would enjoy lower fuel expenses, but the higher purchase prices would produce a larger increase in average annual capital expenses.

The average fuel price for the Midwest region at the time of Gurciullo's analysis was $2.023 per gallon, according to the U.S. Energy Information Administration (2017), They also show that diesel hit a high of $4.705 in 2008, and are currently on the rise again. $3.50 per gallon may be a reasonable estimation of future diesel prices, and average prices have been above this mark as recently as December 2014, according to the U.S Energy Information Administration data set. If a diesel price of $3.50 is used, electric buses show an immediate 12-year life-cycle benefit of $138,116 and $288,116 per bus when considering a diesel bus purchase price of $300,000 and $450,000, respectively, before considering any effects on externalities. Cost competitiveness of electric buses at current purchase prices occurs when diesel is at $2.90 per gallon if the diesel bus purchase price is $300,000, or when diesel is at $2.24 per gallon if the diesel bus purchase price is $450,000. Gurciullo (2016) estimated the public health benefits of eliminating diesel buses' local emissions to be $55,000 per bus-year in Chicago, due to lower incidence of respiratory illnesses. Over the 12-year life of a bus, this implies $660,000 in human health savings per bus. Including this social cost savings suggests that each electric bus provides a net benefit of $460,000 or $610,000 over a 12-year lifespan, assuming a $300,000 or $450,000 diesel-bus purchase price, respectively. However, the public health benefits are experienced by the public, not directly by the transit agency, meaning additional funding would still be necessary to shift to electric propulsion at current prices.

Additional costs would be incurred beyond what is analyzed in this report. Charging infrastructure would be needed, either at centralized locations, en-route, or both. The costs of such infrastructure are difficult to estimate, since they depend on the charging strategies and facilities an agency employs. This cost would be partially offset by reductions in diesel fueling facilities, especially once a bus fleet is fully converted. The range the electric buses can travel on a full or partial charge also affects costs. If there are routes in Capital Metro's system that demand more miles per day from some buses than they can achieve on one charge, accommodations will be needed. This may mean purchasing more buses, changes in bus scheduling, and/or purchasing buses with additional battery capacity, all of which can increase costs. Alternatively, charging strategies and infrastructure could be tailored to allow for charging to occur en-route and at route ends to extend the buses' range enough to meet their service demands. Lajunen and Lipman (2016) find that employing en-route charging is more cost-effective than using strictly overnight charging. Additionally, electric vehicles are generally considered to have lower maintenance costs than their internal combustion counterparts, though actual numbers were not readily found for transit buses, likely owing to the infancy of the use of battery-electric buses.

10.1.1 Future Cost Analysis

The cost of electric buses, and battery-electric vehicles in general, is falling. According to Gurciullo (2016), CTA paid $1 million per electric bus in 2014, so their 2016 purchase at $800,000 represents a 20% total price decrease in two years, or a 10.56% annual reduction. Nykvist and Nilsson (2015) reveal that electric vehicle battery pack costs are falling by 14% annually. Based on the two-year price reduction of $200,000 for an electric bus, this would indicate that the battery packs constitute $567,395 of an $800,000 electric bus. This means that the bus' non-battery costs are $232,604, which is reasonable, since battery packs are the most significant portion of the cost of electric powertrains (Nykvist and Nilsson, 2015), especially in vehicles requiring significant battery capacity, like buses. Electric buses have been introduced to the market with a 200-mile range (BYD Auto Co., 2017), which would be sufficient to provide full-day service on many routes, including 70% of Capital Metro's (Borowski, 2017), though en-route charging could extend the range further.

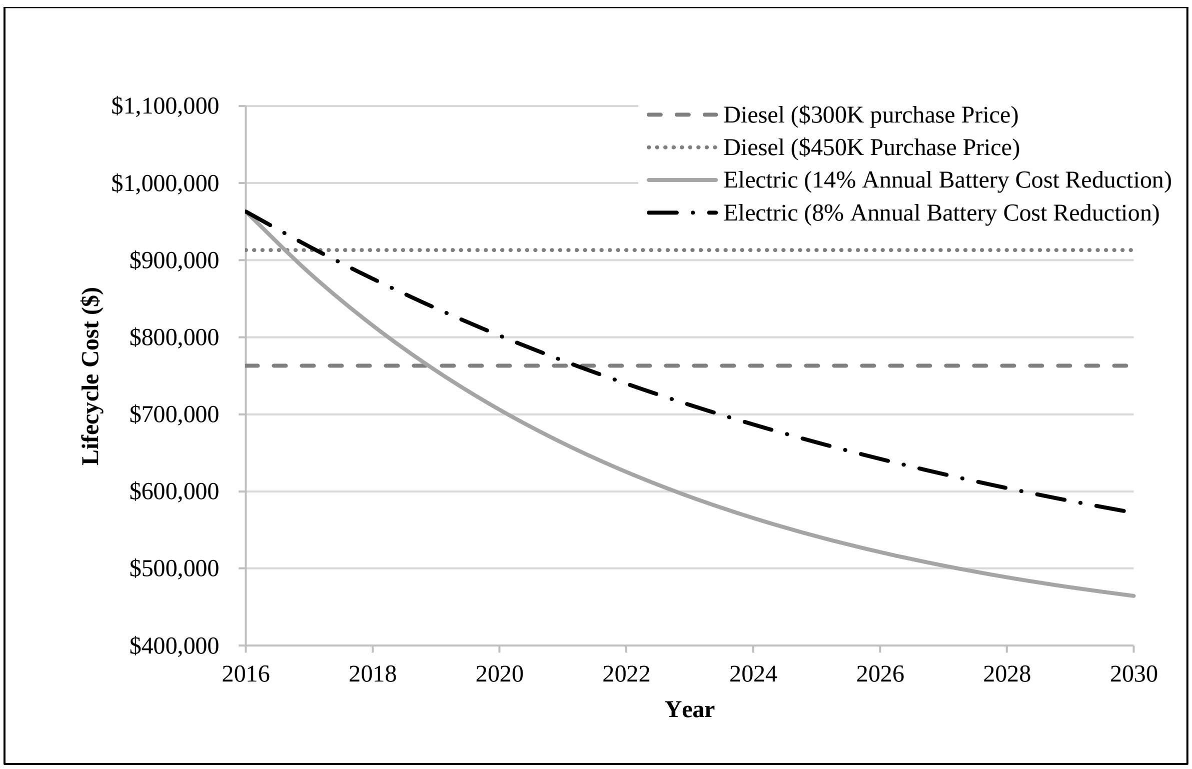

Figure 10.1: Total Life-cycle Cost vs. Purchase Year for Diesel and Electric Powertrains

If the 14% annual reduction in battery pack costs continues, electric bus purchase prices would fall an additional $206,500 by 2019, as shown in Figure 10.1, which would make them competitive with diesel power from a life-cycle cost perspective, assuming a $300,000 diesel bus purchase price. If diesel buses carry a $450,000 purchase price, this cost-competitiveness is reached in 2017. Nykvist and Nilsson (2015) indicate that the leading manufacturers of battery-electric cars are experiencing a lower rate of cost reduction for battery packs, about 8%. As Figure 10.1 shows, if battery pack cost reductions for buses slow to this rate, the $200,000 cost reduction would be surpassed, achieving life-cycle competitiveness with diesel power, by 2022 or 2018 for diesel bus purchase prices of $300,000 and $450,000, respectively. For comparison, Lajunen and Lipman (2016) estimate that electric buses may have lower total life-cycle costs than diesel by 2023 and could present a 20% life-cycle cost benefit over diesel buses by 2030, whereas the constant 8% annual battery cost reduction would yield a 25% life-cycle cost benefit in 2030 when using the more typical $300,000 purchase price for diesel buses.

10.1.2 Qualitative Effects

A conversion to electric propulsion would have additional effects, which are not easily monetized by the information currently available. Anticipated respiratory health benefits are discussed in the cost analysis section, since a monetized analysis has been performed. However, local emissions produced by diesel buses have wide ranging effects beyond respiratory health. These emissions are often expelled within a few feet of passengers alighting or waiting at bus stops, which can make the air unpleasant to breathe for these passengers and others in the area. Additionally, the diesel engine produces a considerable amount of noise and heat that can be unpleasant for the same people. These two factors may dissuade potential riders, especially those who may be sensitive to these factors, and may negatively influence the public opinion of bus service.

The burning of fossil fuels is widely known to contribute to climate change through the emission of greenhouse gases, and diesel buses contribute to this negative environmental impact. Though a fully loaded bus may provide some per-passenger greenhouse gas emission reduction compared to typical personal vehicles, the climate change impact of public transportation should not be ignored. Electric propulsion has the potential to significantly reduce the greenhouse gas emissions of transit buses, as well as overall air pollution emissions. Lajunen and Lipman (2016) conclude that electric buses could reduce emissions of the greenhouse gas carbon dioxide by 75%, though the amount of the benefit is dependent on the source of the electricity used to charge the buses.

Emissions from electric buses in Austin would depend on Austin's electricity sources. Austin Energy, the city's lone electric utility, maintains ownership stakes in power generation projects throughout Texas to cover its electricity demand, and makeup of the utility's generation included 20.68% renewable energy in 2013, more than double the ERCOT grid average (Austin Energy, 2014). Austin Energy also has commitments to transition more of its electricity production to renewable sources, with 450 MW in solar energy scheduled to come on line, and a generation plan that calls for the installation of 950 MW of solar capacity by 2025 (Maloney, 2016). The utility has also committed to decommissioning its only coal plant, the Fayette Power Project, by 2022 (Hicks, 2016). Overall, Austin Energy plans to generate 55% of its electricity from renewable sources by 2025 (Maloney, 2016). This sharp increase in renewable power implies a significant reduction in greenhouse gas emissions and overall pollution emissions resulting from electricity consumed in Austin, including what would be used to power electric buses.

Figure 10.2: A New Flyer Battery-Electric Bus Charging in Winnipeg (Winnipeg Transit, n.d.)

10.2 Autonomous Buses

Though fully autonomous vehicles are not yet widely available, predictions exist of potential price premiums for the technology. Estimates of the technology cost for buses are hard to find, but it is reasonable to expect that the large size of transit buses may necessitate the use of additional sensors, and therefore, higher cost than for personal vehicles. This section uses what estimates are available to analyze and discuss the costs associated with implementation of fully autonomous technology in buses. Qualitative effects of implementation are also discussed.

10.2.1 Driver Costs

The biggest financial benefit of fully autonomous buses to public transit agencies is the potential for reduction in driver costs. To meet its current driving needs, Capital Metro contracts with two outside companies, which manage and provide drivers for all bus routes, at a total cost of $118.9 million annually (Capital Metro, 2016a). This is 45% of the agency's operating budget, and translates to an annual average of $271,456 per bus in their fleet. Over a 12-year bus life, $3.26 million in driver expenses would be paid, so there is ample room for cost savings if self-driving buses can replace the need for drivers. Though drivers may become unnecessary, there may still be a need for roving attendants to create a sense of safety and check fares, though they would be needed in much smaller numbers than drivers currently are.

The cost of fully autonomous technology, as well as the additional cost for large vehicles like buses, is largely unknown since the technology is not yet on the market, and predictions vary widely. Bansal and Kockelman (2017a) estimated the technology premium (i.e., added cost) in the early years of availability to be $40,000 for a passenger (light-duty) vehicle, based on expert opinions. This report uses a conservative estimate of $80,000 for the added cost of delivering a self-driving bus, which is twice that of a personal vehicle. With this estimate, the total life-cycle savings from implementing fully autonomous technology to completely replace human drivers would be $3.18 million per 12-year (expected scrappage) age of a CapMetro bus, which averages to $265K per bus annually, or $116 million in annual budget savings for an agency like CapMetro, with 438 buses. With a shift to autonomous driving technologies, more technical support would likely be necessary, to check sensors and address technology issues on site. The extent and cost of such support is uncertain, but it will presumably be small, compared to existing driver costs.

10.2.2 Additional Effects

Self-driving buses can provide benefits beyond a dramatic reduction in or elimination of driver costs. Autonomous technology is expected to improve safety (by employing many cameras, radar, mapping software, and Lidar in and around the vehicle), while smoother fully autonomous driving may improve fuel efficiency, emissions, and rider comfort. The autonomous technology currently being tested has a good safety record, and has the potential to be significantly safer than human drivers (Fagnant and Kockelman, 2016). Improving the safety record of transit buses would lower operation costs through lower insurance and crash expenses, in addition to the qualitative effects that improved safety can provide.

Silberg et al. (2017) estimate that fully autonomous technology can lower overall crash expenses for private vehicles by 40%. Transit buses may not see a reduction as extreme, since their drivers are trained professionals. The smoother driving provided by fully autonomous technology can reduce fuel consumption (Liu and Kockelman, 2017; Fagnant and Kockelman, 2016). With the use of electric power, this translates to lower energy consumption and increased range per charge. Regardless of power source, fuel or energy costs should fall. Lower fuel consumption, in addition to smoother acceleration, would also mean a reduction in harmful emissions, leading to a potential improvement in local air quality. Energy use and emissions may decrease 10% in light-duty vehicles (Liu, 2017), though the benefits may differ some for autonomous buses replacing experienced professional drivers. Smoother driving can also improve the ride comfort by reducing some of the jerking of the vehicle associated with human driving. If the cost savings of automation, are used partially to increase frequencies, transit service could become more attractive.

10.2.3 Co-Implementation of Electrification and Automation

Once fully autonomous technology becomes available for full-size buses, electric propulsion and autonomous technology could be implemented simultaneously, as autonomous electric buses. The smoother driving and lower energy consumption provided by fully autonomous technology may extend the range each bus can drive on a single charge. In the short term, the potential cost savings from fully autonomous buses could allow for earlier adoption of electric buses by offsetting added costs associated with electric propulsion. In the future, once electric propulsion offers life-cycle cost savings over diesel, implementing both technologies would realize the maximum possible cost reduction.

Chapter 11: Adoption Schedules

Due to existing investments and commitments, there is a limited number of buses that would realistically be converted to electric power annually, since it is most agencies' interest to not retire large capital investments (like buses) early. Likewise, existing labor contracts with drivers must be honored. Here, an implementation schedule is developed for each technology, taking these factors into account.

11.1 Electric Bus Adoption Schedule

In this analysis, a 12-year life for each bus is used, which equates to Capital Metro replacing 36.5 buses in the average year. It is assumed that every new bus purchased is electric, beginning in 2017. The analysis is performed with two electric-bus adoption scenarios, with one representing a 14% annual reduction in battery costs, and the other representing the more conservative 8% annual reduction in battery costs, and repeated for both a $300,000 and $450,000 diesel bus purchase price.

11.2 Autonomous Bus Adoption Schedule

Due to existing driver contracts and labor agreements, it is not assumed that agencies like Capital Metro can lay off drivers at will. Since the terms and length of these contracts and the average driver's career duration are not known, it is assumed that a self-driving bus cannot be put into service until a driver retires. Assuming that each driver drives for 20 years, five percent of an agency's drivers may retire in the average year. In reality, some bus drivers have much longer careers, but after 20 years of not hiring new drivers, driver numbers may be low enough that the few who remain can be assigned to other duties, such as paratransit services, where humans may still be needed to assist customers with disabilities. The 12-year maximum bus life is still used though human-driven buses are allowed to be retired earlier in favor of fully autonomous buses if the driver retires, since the driver savings far outweigh the purchase price of the bus.

11.3 Co-Adoption Schedule

For the co-adoption scenario (of both automation and electrification, for each new bus), the same assumptions from the previous two sections are used. Analysis begins in 2017, which is unrealistic for adoption of fully autonomous technology, but demonstrates an adoption schedule for simultaneous adoption. Since battery costs will be higher in 2017 than in later years, this early start year provides the most conservative estimate of how long it will take to reach the break-even point in cumulative costs.

11.4 Results

For each scenario, bus purchase costs, driver costs, and fuel costs are tracked for each year for 20 years, and the accumulated totals are calculated.

Table 11.1: Cumulative (Life-Cycle) Costs for 14% and 8% per-Year Battery Cost Reductions

	Cumulative Purchase, Fuel, and Driver Costs (in $1 Million) for Capital Metro's Fleet							
	No Action		Full-AV Adoption Only		Electric Adoption Only		Co-Adoption	
Year	*$300K diesel*	*$450K diesel*	*$300K diesel*	*$450K diesel*	*14% reduction*	*8% reduction*	*14% reduction*	*8% reduction*
2017	**$146.8**	***$152.2***	**$142.6**	***$148.0***	$161.2	$162.4	$183.3	$185.8
2018	$293.5	$304.5	$279.2	$290.1	$319.0	$322.4	$354.8	$361.7
2019	$440.3	$456.7	$409.8	$426.3	$473.7	$480.1	$515.1	$527.9
2020	$587.0	$608.9	$534.6	$556.5	$625.7	$635.6	$664.8	$684.7
2021	$733.8	$761.1	$653.3	$680.7	$775.1	$789.0	$804.6	$832.2
2022	$880.5	$913.4	$766.2	$799.0	$922.3	$940.3	$934.7	$970.7
2023	$1,027	***$1,066***	$873.1	$911.4	$1,067	$1,090.	***$1,056***	$1,100.
2024	**$1,174**	***$1,218***	$974.0	$1,018	***$1,211***	$1,237	**$1,168**	$1,221
2025	$1,321	***$1,370.***	$1,069	$1,118	$1,352	$1,383	$1,271	***$1,334***
2026	**$1,468**	$1,522	$1,158	$1,213	$1,492	$1,527	$1,366	**$1,438**
2027	$1,614	***$1,674***	$1,241	$1,301	$1,630.	***$1,670.***	$1,453	$1,533
2028	$1,761	$1,827	$1,318	$1,384	$1,767	$1,811	$1,532	$1,621
2029	**$1,908**	$1,979	$1,394	$1,466	**$1,903**	$1,951	$1,608	$1,706
2030	$2,055	$2,131	$1,463	$1,542	$2,039	$2,091	$1,678	$1,784
2031	$2,201	$2,283	$1,526	$1,611	$2,174	$2,230.	$1,740.	$1,855
2032	$2,348	$2,436	$1,583	$1,675	$2,310.	$2,369	$1,796	$1,919
2033	$2,495	$2,588	$1,635	$1,733	$2,444	$2,507	$1,846	$1,976
2034	$2,642	$2,740.	$1,680.	$1,785	$2,579	$2,645	$1,889	$2,026
2035	**$2,788**	$2,892	$1,720.	$1,831	$2,714	**$2,783**	$1,926	$2,069
2036	$2,935	$3,045	$1,753	$1,871	$2,848	$2,920.	$1,956	$2,106

As shown in Table 11.1, the cumulative costs for adoption (beginning in year 2017) surpass a break-even point for the adoption of electric technology at a 14% annual battery cost reduction in year 2029 or 2024, assuming $300,000 and $450,000 diesel bus purchase price, respectively. The timing shifts earlier, to 2024 or 2023, respectively, if fully autonomous technology is adopted simultaneously (on the same, new-bus purchases). The break-even point for electric-only adoption at 8% annual battery cost reduction occurs in 2035 or 2027, respectively, and co-adoption moves this timing to year 2026 or 2025, respectively. Autonomous-only adoption delivers a net savings immediately (within the first year of technology adoption), regardless of the diesel bus purchase price assumed here ($300,000 or $450,000 per new, standard bus acquired).

Chapter 12: Conclusions for Part Three

Based on analysis of direct costs, battery-electric buses are not yet life-cycle cost-competitive with diesel-powered buses, while fully-automated buses (without a driver or full-time attendant) should be cost-competitive immediately. However, electric bus purchase prices are falling, primarily due to falling battery prices, and this should make electric buses life-cycle cost-competitive within the next few years. Electric buses can also provide various social benefits that do not appear in an agency's budget, via improved service quality, public health and other environmental benefits, and public perceptions. Battery-electric buses should be thoughtfully evaluated by all U.S. agencies for coming purchases. Some transit agencies may be currently paying much more or less for diesel buses than the prices used in this analysis. Austin's Capital Metro adds options to diesel buses that increase their price significantly, and European and other transit agencies may experience much higher diesel prices than U.S. agencies do, potentially making battery-electric buses more attractive than diesel counterparts in many settings.

Though their technology premium remains uncertain (and use of en-route bus attendants remains uncertain), fully autonomous buses will almost certainly exhibit a life-cycle savings over their human-driven counterparts. Transit agencies generally have contracts with their drivers, but the anticipated savings from adoption of self-driving buses are significant enough that transit agencies could afford to offer significant contract buyouts to accelerate adoption, and still realize substantial savings. In addition to lower costs, self-driving buses offer the potential to improve the quality of service (possibly including through smaller buses, offering at higher frequency, for example), reduce fuel consumption and emissions, and operate more safely than their human-driven counterparts. Further, the budget improvements afforded by fully autonomous technology could be used to expand or otherwise improve transit-system service and provide the funds for adoption of electric (self-driving) buses. Fully autonomous vehicles appear to be the way of the future, and it is important that transit agencies begin planning for their use, along with electrified buses.

Appendix A: Simulation Code

```
%MATLAB program to simulate fleet evolution, VMT, and home location until
%year 2050
clc
clear
input=xlsread('US.xlsx');
%input=input(1:3,:); % for test
[techinput,techheader]=xlsread('Tech_price_10_Per.xlsx');
techprice=techinput(2,:);
techprice_used=techprice;
[respon,~]=size(input);
Time=34; % in years

%Households WTP for all iterations
WTPbase=zeros(respon,15);
VMT = zeros(respon, Time);
VMTpsav = zeros(respon, Time);
VMTdrs = zeros(respon, Time);
VMT_vehicles = zeros(respon, Time);
Vage = zeros(respon, 15, Time);
VMTknom = zeros(respon, 15, Time);
VMTtnom = zeros(respon, Time);
VMTrat = zeros(respon, Time);
VMTk = zeros(respon, 15, Time);
VMTpAVdiesel = zeros(respon, Time);
VMTpAVdieselYEAR = zeros(Time);
VMTpAVgas = zeros(respon, Time);
VMTpAVgasYEAR = zeros(Time);
VMTpAVhev = zeros(respon, Time);
VMTpAVhevYEAR = zeros(Time);
VMTpAVphev = zeros(respon, Time);
VMTpAVphevYEAR = zeros(Time);
VMTpAVbev = zeros(respon, Time);
VMTpAVbevYEAR = zeros(Time);
VMThvDIESEL = zeros(respon, Time);
VMThvDIESEL_YEAR = zeros(Time);
VMThvGAS = zeros(respon, Time);
VMThvGAS_YEAR = zeros(Time);
VMThvHEV = zeros(respon, Time);
VMThvHEV_YEAR = zeros(Time);
VMThvPHEV = zeros(respon, Time);
VMThvPHEV_YEAR = zeros(Time);
VMThvBEV = zeros(respon, Time);
VMThvBEV_YEAR = zeros(Time);
VMT_YEAR = zeros(Time);
VMTpsavYEAR = zeros(Time);
VMTdrsYEAR = zeros(Time);
VMT_vehiclesYEAR = zeros(Time);

BACHELORS = input(:,1);
DOWNTOWN_DIST = input(:,2);
DA_TO_WORK = input(:,3);
FULL_TIME= input(:,4);
HHSIZE= input(:,5);
MALE= input(:,6);
POPDENS= input(:,7);
RETIRED= input(:,8);
MARRIED= input(:,9);
NOT_DISABILED= input(:,11);
HHINCOME= input(:,12);
HHWORKERS= input(:,10);
LICENSE= input(:,13);
TRANSIT_DIST= input(:,14);
HHCHILDREN= input(:,24);
```

```
prob_Acquire= input(:,25);
PART_TIME= input(:,26);
STUDENT= input(:,27);
UNEMPLOYED= input(:,28);
WORKSCHOOL_DIST= input(:,29);
GROCERY_DIST= input(:,30);
WHITE= input(:,31);

% update after each year
AGE=zeros(respon,Time);
IND_AGE_OLDEST_VEH=zeros(respon,Time);
IND_AVG_VEH_HOLD_TIME=zeros(respon,Time);
NUM_VEH_OWNED=zeros(respon,Time);
NUM_VEH_SOLD=zeros(respon,Time);% number of vehicles sold in the past 10 years
TOT_VEH_SOLD=zeros(respon,Time); % total number of vehicles sold in the past
SOLD_VEH_IND=zeros(respon,Time);

DTdist=zeros(respon,Time); % Matrix of distance to downtown for each hh for each year

OWNED_VEH_IND=zeros(respon,Time);
TRANSACTION=zeros(respon,Time);
AGE(:,1)= input(:,16); %input is a random age within the specified range to avoid a large number of people reaching the maximum age and being replaced with youngsters in some years and no rollovers (just aging of the population by 1 year on average) in other years
IND_AGE_OLDEST_VEH(:,1)= input(:,17);
IND_AVG_VEH_HOLD_TIME(:,1)= input(:,18);
NUM_VEH_OWNED(:,1)= input(:,19);
NUM_VEH_SOLD = zeros(respon,Time);
TOT_VEH_SOLD(:,1)=NUM_VEH_SOLD(:,1);
OWNED_VEH_IND(:,1)= input(:,21);
TRANSACTION(:,1)= input(:,22);
SOLD_VEH_IND(:,1)=input(:,23);
VMT(:,1)= input(:,15);

hhcurrveh = zeros(Time,respon,6,16);
hhsoldveh = zeros(Time,respon,6,16);
% 4d array (Time,Household,vehicle,attributes) for current vehicles
for j=1:respon
    j
    DTdist(j,1)=DOWNTOWN_DIST(j,1);
    if NUM_VEH_OWNED(j,1) > 0
        for k=1:NUM_VEH_OWNED(j,1)
            hhcurrveh(1,j,k,1)=input(j,31+k); % manufacture year
            hhcurrveh(1,j,k,2)=input(j,37+k); % acquisition year
            if(hhcurrveh(1,j,k,2)-hhcurrveh(1,j,k,1)>0)
                hhcurrveh(1,j,k,3)=0; % new (indicator)
            else
                hhcurrveh(1,j,k,3)=1;
            end
            if input(j,43+k)==1||input(j,43+k)==3||input(j,43+k)==4
                hhcurrveh(1,j,k,4)=1; % Gasoline
            elseif input(j,43+k)==2
                hhcurrveh(1,j,k,5)=1; % Diesel
            elseif input(j,43+k)==5
                hhcurrveh(1,j,k,6)=1; % HEV
            elseif input(j,43+k)==6
                hhcurrveh(1,j,k,7)=1; % PHEV
            elseif input(j,43+k)==7
                hhcurrveh(1,j,k,8)=1; % BEV
            end
            hhcurrveh(1,j,k,16)=0; % Level 4
        end
    else
        hhcurrveh(1,j,1,:)=zeros(16,1);
    end
end
% 4d array (Time,Household,vehicle,attributes) for sold vehicles
for j=1:respon
```

```
    j
    if NUM_VEH_SOLD(j,1) > 0
        for k=1:NUM_VEH_SOLD(j,1)
            hhsoldveh(1,j,k,1)=input(j,49+k); % sell year
            hhsoldveh(1,j,k,2)=input(j,55+k); % acquisition year
            if(hhsoldveh(1,j,k,2)-hhsoldveh(1,j,k,1)>0)
                hhsoldveh(1,j,k,3)=0; % new (indicator)
            else
                hhsoldveh(1,j,k,3)=1;
            end
            hhcurrveh(1,j,k,4)=input(j,43+k); % 1=ICE, 2=HEV, 3=PHEV, 4=BEV
            hhsoldveh(1,j,k,16)=0; % Level 4
        end
    else
        hhsoldveh(1,j,k,:)=zeros(16,1);
    end
end

%Private SAV percent decision Logit
ascPSAV = -0.4622;
betaPSAV_MALE_IND = -0.0574;
betaPSAV_LICENSE = -0.1112;
betaPSAV_AGE = -0.00395;
betaPSAV_HHSIZE = -0.0164;
betaPSAV_HHWORKERS = 0.1039;
betaPSAV_WHITE = -0.0772;
betaPSAV_FULL_TIME = -0.5706;
betaPSAV_PART_TIME = -0.3103;
betaPSAV_STUDENT = -0.2257;
betaPSAV_UNEMPLOYED = -0.3086;
betaPSAV_RETIRED = -0.1951;
betaPSAV_MARRIED = 0.1238;
betaPSAV_HHVEHICLES = -0.0696;
betaPSAV_VEH_PURCH_PROB = 0.00722;
betaPSAV_GROCERY_DIST = -0.00920;
betaPSAV_DOWNTOWN_DIST = 0.000974;
betaPSAV_INCOME = -0.00022;
betaPSAV_NO_DISABILITY = -0.3016;
betaPSAV_WORK_SCHOOL_DIST = 0.00833;
betaPSAV_BACHELORS = 0.1419;
betaPSAV_DA_TO_WORK = 0.0496;
betaPSAV_POPDENS = 0.1305;

%DRS percent decision Logit
ascDRS = -1.2387;
betaDRS_MALE_IND = 0.0705;
betaDRS_LICENSE = -0.1300;
betaDRS_AGE = -0.0125;
betaDRS_HHCHILDREN = 0.0733;
betaDRS_HHWORKERS = 0.1254;
betaDRS_WHITE = -0.0866;
betaDRS_FULL_TIME = 0.1508;
betaDRS_PART_TIME = 0.3469;
betaDRS_STUDENT = 0.4641;
betaDRS_UNEMPLOYED = 0.1637;
betaDRS_RETIRED = 0.3221;
betaDRS_MARRIED = -0.0397;
betaDRS_HHVEHICLES = -0.1760;
betaDRS_VEH_PURCH_PROB = 0.00847;
betaDRS_GROCERY_DIST = 0.0126;
betaDRS_TRANSIT_DIST = -0.00723;
betaDRS_DIST_DOWNTOWN = -0.00219;
betaDRS_INCOME = 0.000864;
betaDRS_NO_DISABILITY = -0.3916;
betaDRS_WORK_SCHOOL_DIST = 0.00773;
betaDRS_BACHELORS = 0.1868;
betaDRS_DA_TO_WORK = -0.0676;
```

```
betaDRS_POPDENS = 0.0601;

%Acquisition decision MNL model specification (w/o owned vehicle)
ascAcq = -2.699192;
betaAcq_MALE = 0.4632;
betaAcq_LICENSE = -0.4918;
betaAcq_HHCHILDREN = 0.2512;
betaAcq_HHINCOME = 0.00417;
betaAcq_WHITE = -0.2105;
betaAcq_STUDENT = 0.4544;
betaAcq_UNEMPLOYED = 0.3789;
betaAcq_TRANSIT_DIST = -0.0167;
betaAcq_DA_TO_WORK = 0.1826;

%Acquisition decision MNL model specification (w/ owned vehicle)
ascAcq = -1.698802;
betaAcq_MALE = 0.4634;
betaAcq_LICENSE = -0.6230;
betaAcq_HHCHILDREN = 0.2400;
betaAcq_HHINCOME = 0.00424;
betaAcq_WHITE = -0.2903;
betaAcq_STUDENT = 0.4467;
betaAcq_UNEMPLOYED = 0.3919;
betaAcq_TRANSIT_DIST = -0.0161;
betaAcq_DA_TO_WORK = 0.1583;
betaAcq_IND_AGE_OLDEST_VEH = -0.00592;

%Release decision MNL model specification (w/o owned vehicle)
ascRel = -2.51;
betaRel_LICENSE = -0.4829;
betaRel_HHISIZE = -0.1469;
betaRel_WHITE = 0.3464;
betaRel_RETIRED = 0.3072;
betaRel_MARRIED = 0.2153;
betaRel_VEH_PURCH_PROB = 0.0253;
betaRel_TRANSIT_DIST = -0.0125;
betaRel_NO_DISABILITY = 0.4042;
betaRel_DA_TO_WORK = 0.3555;

%Release decision MNL model specification (w/ owned vehicle)
ascRel = -1.90774;
betaRel_LICENSE = -0.7256;
betaRel_HHISIZE = -0.1589;
betaRel_WHITE = 0.2737;
betaRel_RETIRED = 0.3103;
betaRel_MARRIED = 0.2221;
betaRel_VEH_PURCH_PROB = 0.0259;
betaRel_TRANSIT_DIST = -0.0141;
betaRel_NO_DISABILITY = 0.4181;
betaRel_DA_TO_WORK = 0.3242;
betaRel_IND_AGE_OLDEST_VEH = -0.00645;

%Binary logit model estimates for bought new? - This is currently used vs. new SUsedNotNew
ascUSED = 1.7654;
betaUSED_MALE = -0.4482;
betaUSED_LICENSE = -0.7955;
betaUSED_AGE = -0.0151;
betaUSED_HHSIZE = 0.0952;
betaUSED_HHWORKERS = 0.2478;
betaUSED_INCOME = -0.00944;
betaUSED_WHITE = 0.5724;
betaUSED_BACHELORS = -0.3052;
betaUSED_FULL_TIME = -0.5810;
betaUSED_RETIRED = -0.2878;
betaUSED_MARRIED = -0.2338;
betaUSED_VEH_PURCH_PROB = -0.0102;
betaUSED_WORKSCHOOL_DIST = 0.0164;
```

```
betaUSED_DOWNTOWN_DIST = -0.00967;
betaUSED_DA_TO_WORK = -0.3764;
betaUSED_POPDENS = 0.5027;


%Multinomial logit model estimates for MNL powertrain decision (gasoline is baseline)
ascDIESEL = -1.2;
ascHEV = 2.4870;
ascPHEV = 1.5322;
ascBEV = -1.3754;
betaDIESEL_MALE = -1.0120;
betaDIESEL_HHCHILDREN = -0.5575;
betaDIESEL_AGE = 0.0192;
betaDIESEL_HHSIZE = 0.1476;
betaDIESEL_BACHELORS = -0.8427;
betaDIESEL_MARRIED = -0.3815;
betaDIESEL_VEH_PURCH_PROB = -0.0134;
betaDIESEL_GROCERY_DIST = -0.0618;
betaDIESEL_TRANSIT_DIST = 0.0338;
betaDIESEL_WORKSCHOOL_DIST = 0.00605;
betaDIESEL_NO_DISABILITY = 0.4334;
betaDIESEL_DA_TO_WORK = 0.0239;
betaHEV_MALE = -1.0204;
betaHEV_HHCHILDREN = -0.3132;
betaHEV_AGE = 0.0215;
betaHEV_HHSIZE = 0.0106;
betaHEV_BACHELORS = -0.3438;
betaHEV_MARRIED = -0.6301;
betaHEV_VEH_PURCH_PROB = -0.0168;
betaHEV_GROCERY_DIST = -0.0854;
betaHEV_TRANSIT_DIST = 0.00949;
betaHEV_WORKSCHOOL_DIST = -0.0274;
betaHEV_NO_DISABILITY = 0.1166;
betaHEV_DA_TO_WORK = 0.5808;
betaPHEV_MALE = -1.4769;
betaPHEV_HHCHILDREN = -0.6548;
betaPHEV_AGE = 0.0128;
betaPHEV_HHSIZE = 0.2421;
betaPHEV_BACHELORS = -0.4072;
betaPHEV_MARRIED = -0.2124;
betaPHEV_VEH_PURCH_PROB = -0.0191;
betaPHEV_GROCERY_DIST = -0.0495;
betaPHEV_TRANSIT_DIST = 0.0288;
betaPHEV_WORKSCHOOL_DIST = -0.0311;
betaPHEV_NO_DISABILITY = 0.9088;
betaPHEV_DA_TO_WORK = 0.4714;
betaBEV_MALE = -0.6774;
betaBEV_HHCHILDREN = -1.1133;
betaBEV_AGE = 0.0111;
betaBEV_HHSIZE = 0.6196;
betaBEV_BACHELORS = -0.3376;
betaBEV_MARRIED = 0.0102;
betaBEV_VEH_PURCH_PROB = -0.00372;
betaBEV_GROCERY_DIST = 0.00310;
betaBEV_TRANSIT_DIST = -0.0201;
betaBEV_WORKSCHOOL_DIST = -0.0210;
betaBEV_NO_DISABILITY = 0.3269;
betaBEV_DA_TO_WORK = 0.3798;

% Moving direction - ordered probit (1 is 2 units closer to 5 is 2 units farther away) (1 [two units closer] is baseline)
hcutTWOFAR = -1.2022;
hcutONEFAR = 0.0243;
hcutSAME = 0.8994;
hcutONECLOSE = 1.4854;
betaMOVEDIR_MALE = -0.3690;
betaMOVEDIR_HHCHILDREN = -0.2413;
betaMOVEDIR_HHSIZE = 0.1229;
```

```
betaMOVEDIR_FULL_TIME = -0.7068;
betaMOVEDIR_PART_TIME = -0.7865;
betaMOVEDIR_STUDENT = -0.7490;
betaMOVEDIR_UNEMPLOYED = -0.7614;
betaMOVEDIR_RETIRED = -0.6409;
betaMOVEDIR_HHVEHICLES = 0.1085;
betaMOVEDIR_VEH_PURCH_PROB = -0.00226;
betaMOVEDIR_WORKSCHOOL_DIST = -0.0109;
betaMOVEDIR_NO_DISABILITY = 0.2959;
betaMOVEDIR_DA_TO_WORK = 0.1670;

%Choose AV - Logit
ascAV = 0.9451;
betaAV_MALE = 0.3352;
betaAV_LICENSE = -0.4182;
betaAV_AGE = -0.0309;
betaAV_HHINCOME = 0.00329;
betaAV_WHITE = -0.2992;
betaAV_BACHELORS = 0.2885;
betaAV_FULL_TIME = -0.3376;
betaAV_UNEMPLOYED = -0.4770;
betaAV_MARRIED = 0.2842;
betaAV_HHVEHICLES = -0.1676;
betaAV_VEH_PURCH_PROB = 0.0112;
betaAV_DT_DIST = 0.0131;
betaAV_NO_DISABILITY = -0.7502;

%Buy vs. lease - Logit
ascBUY = 0.0142;
betaBUY_LICENSE = 0.5886;
betaBUY_AGE = 0.0216;
betaBUY_HHSIZE = 0.2628;
betaBUY_HHWORKERS = -0.3574;
betaBUY_FULL_TIME = 0.4862;
betaBUY_PART_TIME = 0.4140;
betaBUY_GROCERY_DIST = 0.0725;

%Move or not - Logit
ascMOVE = 1.0755;
betaMOVE_MALE = -0.2567;
betaMOVE_AGE = -0.0435;
betaMOVE_HHCHILDREN = 0.2208;
betaMOVE_HHSIZE = -0.2224;
betaMOVE_HHWORKERS = 0.2817;
betaMOVE_HHVEHICLES = -0.4504;
betaMOVE_VEH_PURCH_PROB = 0.0104;
betaMOVE_TRANSIT_DIST = 0.0147;
betaMOVE_NO_DISABILITY = -0.4490;
betaMOVE_DA_TO_WORK = -0.3519;

%VMT betas (WLS)
ascVMT = 452.51096;
betaVMT_MALE = 519.48560;
betaVMT_HHCHILDREN = 475.81253;
betaVMT_WHITE = 866.84468;
betaVMT_FULL_TIME = 1284.54778;
betaVMT_INCOME = 5.99261;
betaVMT_PART_TIME = 743.21671;
betaVMT_RETIRED = 822.93657;
betaVMT_MARRIED = 796.22157;
betaVMT_LICENSE = 2807.09109;
betaVMT_HHVEHICLES = 468.49963;
betaVMT_VEH_PURCH_YEAR_PROB = 10.27829;
betaVMT_GROCERY_DIST = 58.93861;
betaVMT_WORKSCHOOL_DIST = 90.84609;
betaVMT_DA_TO_WORK = 1679.44863;
```

```
%WTP for AV a
ascWTPA = 14831;
betaWTPA_AGE = -150.31411;
betaWTPA_HHWORKERS = -792.25752;
betaWTPA_HHINCOME = 23.94361;
betaWTPA_WHITE = -1334.79011;
betaWTPA_BACHELORS = -1423.84160;
betaWTPA_FULL_TIME = 1034.02761;
betaWTPA_UNEMPLOYED = -2168.23463;
betaWTPA_MARRIED = 2409.21548;
betaWTPA_HHVEHICLES = -626.95046;
betaWTPA_VEH_PURCH_PROB = 82.96150;

%WTP for AV with HV
ascWTPW = 5142.36990;
betaWTPW_AGE = -53.87493;
betaWTPW_HHCHILDREN = 210.15581;
betaWTPW_HHINCOME = 7.33884;
betaWTPW_STUDENT = -1127.36873;
betaWTPW_UNEMPLOYED = -1127.28322;
betaWTPW_MARRIED = 544.62897;
betaWTPW_HHVEHICLES = -271.91038;
betaWTPW_VEH_PURCH_PROB = 31.05848;
betaWTPW_GROCERY_DIST = 34.51703;
betaWTPW_TRANSIT_DIST = -14.95250;
betaWTPW_NO_DISABILITY = -837.68867;

%WTP for AV without HV
ascWTPO = 4814.35913;
betaWTPO_MALE = 523.80007;
betaWTPO_AGE = -39.19853;
betaWTPO_HHCHILDREN = 372.17870;
betaWTPO_WHITE = -647.87091;
betaWTPO_BACHELORS = 439.34698;
betaWTPO_UNEMPLOYED = -821.90039;
betaWTPO_MARRIED = 534.15936;
betaWTPO_HHVEHICLES = -443.81059;
betaWTPO_VEH_PURCH_PROB = 25.58147;
betaWTPO_GROCERY_DIST = 67.12396;
betaWTPO_DOWNTOWN_DIST = -16.83752;
betaWTPO_NO_DISABILITY = -1176.81319;


%Some variables
VMT_YEAR = zeros(Time,1);
VMTpsav = zeros(respon,Time);
VMTpsavYEAR = zeros(Time,1);
VMTdrs = zeros(respon,Time);
VMTdrsYEAR = zeros(Time,1);
VMTtnom = zeros(respon,Time);
VMThvGAS = zeros(respon,Time);
VMThvGAS_YEAR = zeros(Time);
VMT_vehicles = zeros(respon,Time);
VMT_vehiclesYEAR = zeros(Time,1);
percent_PrivSAV = zeros(respon,Time);
percent_DRS = zeros(respon,Time);
SAVpseudoPrice = zeros(Time);

for i=1:Time
   if (i >= 4) % Adjust to latest predictions of when SAVs will become available
       utility_PrivSAV = ascPSAV + betaPSAV_MALE_IND * MALE(:,1) + betaPSAV_LICENSE * LICENSE(:,1) + betaPSAV_AGE * AGE(:,i) + betaPSAV_HHSIZE * HHSIZE(:,1) + betaPSAV_HHWORKERS * HHWORKERS(:,1) + betaPSAV_WHITE * WHITE(:,1) + betaPSAV_FULL_TIME * FULL_TIME(:,1) + betaPSAV_PART_TIME * PART_TIME(:,1) + betaPSAV_STUDENT * STUDENT(:,1) + betaPSAV_UNEMPLOYED * UNEMPLOYED(:,1) + betaPSAV_RETIRED * RETIRED(:,1) + betaPSAV_MARRIED * MARRIED(:,1) + betaPSAV_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaPSAV_VEH_PURCH_PROB * prob_Acquire(:,i-1) + betaPSAV_GROCERY_DIST * GROCERY_DIST(:,1) + betaPSAV_DOWNTOWN_DIST * DTdist(:,i) + betaPSAV_INCOME * HHINCOME(:,1) + betaPSAV_NO_DISABILITY * NOT_DISABILED(:,1) + betaPSAV_WORK_SCHOOL_DIST *
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WORKSCHOOL_DIST(:,1) + betaPSAV_DA_TO_WORK * DA_TO_WORK(:,1) + betaPSAV_BACHELORS * BACHELORS(:,1) + betaPSAV_POPDENS * POPDENS(:,1);
    utility_DRS = ascDRS + betaDRS_MALE_IND * MALE(:,1) + betaDRS_LICENSE * LICENSE(:,1) + betaDRS_AGE * AGE(:,i) + betaDRS_HHCHILDREN * HHCHILDREN(:,1) + betaDRS_HHWORKERS * HHWORKERS(:,1) + betaDRS_WHITE * WHITE(:,1) + betaDRS_FULL_TIME * FULL_TIME(:,1) + betaDRS_PART_TIME * PART_TIME(:,1) + betaDRS_STUDENT * STUDENT(:,1) + betaDRS_UNEMPLOYED * UNEMPLOYED(:,1) + betaDRS_RETIRED * RETIRED(:,1) + betaDRS_MARRIED * MARRIED(:,1) + betaDRS_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaDRS_VEH_PURCH_PROB * prob_Acquire(:,i-1) + betaDRS_GROCERY_DIST * GROCERY_DIST(:,1) + betaDRS_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaDRS_DIST_DOWNTOWN *DTdist(:,i) + betaDRS_INCOME * HHINCOME(:,1) + betaDRS_NO_DISABILITY * NOT_DISABILED(:,1) + betaDRS_WORK_SCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaDRS_BACHELORS * BACHELORS(:,1) + betaDRS_DA_TO_WORK * DA_TO_WORK(:,1) + betaDRS_POPDENS * POPDENS(:,1);
    SAVpseudoPrice(i)= 140.3379791*(.85^i);
    percent_PrivSAV(:,i) = 0.82729137*((SAVpseudoPrice(i))^-0.326)*(exp(utility_PrivSAV)./(ones(respon,1)+exp(utility_PrivSAV))); % probability of a given mile being private SAV, which corresponds to percent of miles
    percent_DRS(:,i) = 0.82729137*((SAVpseudoPrice(i))^-0.326)*(exp(utility_DRS)./(ones(respon,1)+exp(utility_DRS)));
  else
    percent_PrivSAV(:,i) = 0;
    percent_DRS(:,i) = 0;
  end

    % utility equations
    for j=1:respon
      if NUM_VEH_OWNED(j,i) > 0
        utility_Acquire(j) = ascAcq + betaAcq_MALE*MALE(j,1) + betaAcq_LICENSE*LICENSE(j,1) + betaAcq_HHCHILDREN*HHCHILDREN(j,1) + betaAcq_HHINCOME*HHINCOME(j,1) + betaAcq_WHITE*WHITE(j,1) + betaAcq_STUDENT*STUDENT(j,1) + betaAcq_UNEMPLOYED*UNEMPLOYED(j,1) + betaAcq_TRANSIT_DIST*TRANSIT_DIST(j,1) + betaAcq_DA_TO_WORK*DA_TO_WORK(j,1) + betaAcq_IND_AGE_OLDEST_VEH*IND_AGE_OLDEST_VEH(j,i);
        prob_Acquire(j,i) = exp(utility_Acquire(j))/(1+exp(utility_Acquire(j)));
        utility_Release(j) = ascRel + betaRel_LICENSE*LICENSE(j,1) + betaRel_HHISIZE*HHSIZE(j,1) + betaRel_WHITE*WHITE(j,1) + betaRel_RETIRED*RETIRED(j,1) + betaRel_MARRIED*MARRIED(j,1) + betaRel_VEH_PURCH_PROB*prob_Acquire(j,i) + betaRel_TRANSIT_DIST*TRANSIT_DIST(j,1) + betaRel_NO_DISABILITY*NOT_DISABILED(j,1) + betaRel_DA_TO_WORK*DA_TO_WORK(j,1) + betaRel_IND_AGE_OLDEST_VEH*IND_AGE_OLDEST_VEH(j,i);
      else
        utility_Acquire(j) = ascAcq + betaAcq_MALE*MALE(j,1) + betaAcq_LICENSE*LICENSE(j,1) + betaAcq_HHCHILDREN*HHCHILDREN(j,1) + betaAcq_HHINCOME*HHINCOME(j,1) + betaAcq_WHITE*WHITE(j,1) + betaAcq_STUDENT*STUDENT(j,1) + betaAcq_UNEMPLOYED*UNEMPLOYED(j,1) + betaAcq_TRANSIT_DIST*TRANSIT_DIST(j,1) + betaAcq_DA_TO_WORK*DA_TO_WORK(j,1);
        prob_Acquire(j,i) = exp(utility_Acquire(j))/(1+exp(utility_Acquire(j)));
        utility_Release(j) = ascRel + betaRel_LICENSE*LICENSE(j,1) + betaRel_HHISIZE*HHSIZE(j,1) + betaRel_WHITE*WHITE(j,1) + betaRel_RETIRED*RETIRED(j,1) + betaRel_MARRIED*MARRIED(j,1) + betaRel_VEH_PURCH_PROB*prob_Acquire(j,i) + betaRel_TRANSIT_DIST*TRANSIT_DIST(j,1) + betaRel_NO_DISABILITY*NOT_DISABILED(j,1) + betaRel_DA_TO_WORK*DA_TO_WORK(j,1);
      end
      prob_Release(j,i) = exp(utility_Release(j))/(1+exp(utility_Release(j)));

      display=[i j]
      a=rand();
      b=rand();
      if (a > prob_Acquire(j,i)) && (b <= prob_Release(j)) && (OWNED_VEH_IND(j,i)==1)
        TRANSACTION(j,i)=1; %sell
      elseif (a <= prob_Acquire(j,i)) && (b <= prob_Release(j)) && (OWNED_VEH_IND(j,i)==1)
        TRANSACTION(j,i)=2; %replace
      elseif (a <= prob_Acquire(j,i)) && (b > prob_Release(j))
        TRANSACTION(j,i)=3; %buy
      else
        TRANSACTION(j,i)=5; %no transaction
      end
    end
  % end

  utilityBUYnotLEASE = ascBUY + betaBUY_LICENSE * LICENSE(:,1) + betaBUY_AGE * AGE(:,i) + betaBUY_HHSIZE * HHSIZE(:,1) + betaBUY_HHWORKERS * HHWORKERS(:,1) + betaBUY_FULL_TIME * FULL_TIME(:,1) + betaBUY_PART_TIME * PART_TIME(:,1) + betaBUY_GROCERY_DIST * GROCERY_DIST(:,1);
  utilityUSEDnotNEW = ascUSED + betaUSED_MALE * MALE(:,1) + betaUSED_LICENSE * LICENSE(:,1) + betaUSED_AGE * AGE(:,i) + betaUSED_HHSIZE * HHSIZE(:,1) + betaUSED_HHWORKERS * HHWORKERS(:,1) + betaUSED_INCOME * HHINCOME(:,1) + betaUSED_WHITE * WHITE(:,1) + betaUSED_BACHELORS * BACHELORS(:,1) + betaUSED_FULL_TIME * FULL_TIME(:,1) + betaUSED_RETIRED * RETIRED(:,1) + betaUSED_MARRIED * MARRIED(:,1) + betaUSED_VEH_PURCH_PROB * prob_Acquire(:,i) +
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betaUSED_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaUSED_DOWNTOWN_DIST * DTdist(:,i) +
betaUSED_DA_TO_WORK * DA_TO_WORK(:,1) + betaUSED_POPDENS * POPDENS(:,1);
    prob_BUYnotLEASE = exp(utilityBUYnotLEASE)./(ones(respon,1)+exp(utilityBUYnotLEASE));
    prob_USEDnotNEW = exp(utilityUSEDnotNEW)./(ones(respon,1)+exp(utilityUSEDnotNEW));

    for j=1:respon
        if TRANSACTION(j,i) == 5
            if ((IND_AGE_OLDEST_VEH(j,i)> 20) && (NUM_VEH_OWNED(j,i)> 0))
                TRANSACTION(j,i)=1;
                if (NUM_VEH_OWNED(j,i)-1)==0
                    TRANSACTION(j,i)=2;
                end
            end
        elseif ((TRANSACTION(j,i) == 3) && (IND_AGE_OLDEST_VEH(j,i)> 20) && (NUM_VEH_OWNED(j,i)> 0))
            TRANSACTION(j,i) = 2;
        end

        if AGE(j,i)<80
            AGE(j,i+1)= AGE(j,i)+1;
        else
            AGE(j,i+1)= 18;
        end

        if TRANSACTION(j,i) == 5
            hhcurrveh(i+1,j,:,:)=hhcurrveh(i,j,:,:);
            hhsoldveh(i+1,j,:,:)=hhsoldveh(i,j,:,:);
            IND_AGE_OLDEST_VEH(j,i+1)=IND_AGE_OLDEST_VEH(j,i)+1;
            IND_AVG_VEH_HOLD_TIME(j,i+1)=IND_AVG_VEH_HOLD_TIME(j,i);
            NUM_VEH_OWNED(j,i+1)=NUM_VEH_OWNED(j,i);
            TOT_VEH_SOLD(j,i+1)= TOT_VEH_SOLD(j,i);
            OWNED_VEH_IND(j,i+1)= OWNED_VEH_IND(j,i);
            NUM_VEH_SOLD(j,i+1) =length(find(hhsoldveh(i+1,j,:,1)>=2016+i-10));
            if NUM_VEH_SOLD(j,i+1)>0
                SOLD_VEH_IND(j,i+1)=1;
            else
                SOLD_VEH_IND(j,i+1)=0;
            end
        elseif TRANSACTION(j,i) == 1
            TOT_VEH_SOLD(j,i+1)= TOT_VEH_SOLD(j,i)+1;
            NUM_VEH_OWNED(j,i+1)= NUM_VEH_OWNED(j,i)-1;
            if NUM_VEH_OWNED(j,i+1)>0
                OWNED_VEH_IND(j,i+1)=1;
            end
            veh_ind = find(hhcurrveh(i,j,1:NUM_VEH_OWNED(j,i),1)==min(hhcurrveh(i,j,1:NUM_VEH_OWNED(j,i),1)));  % index of the oldest
vehicle (disposing)
            hhsoldveh(i+1,j,1:TOT_VEH_SOLD(j,i),:)=hhsoldveh(i,j,1:TOT_VEH_SOLD(j,i),:);
            hhsoldveh(i+1,j,TOT_VEH_SOLD(j,i+1),:)=hhcurrveh(i,j,veh_ind(1),:);
            hhsoldveh(i+1,j,TOT_VEH_SOLD(j,i+1),1)=2016+i; % updating selling year of sold vehicle and adding it to sold vehicles
            if veh_ind(1) <  NUM_VEH_OWNED(j,i)  % updating current vehicle inventory
                hhcurrveh(i+1,j,1:(veh_ind(1)-1),:)= hhcurrveh(i,j,1:(veh_ind(1)-1),:);
                hhcurrveh(i+1,j,veh_ind(1):NUM_VEH_OWNED(j,i+1),:)= hhcurrveh(i,j,(veh_ind(1)+1):NUM_VEH_OWNED(j,i),:);
            elseif NUM_VEH_OWNED(j,i)==1
                hhcurrveh(i+1,j,1,:)= zeros(16,1);
            else
                hhcurrveh(i+1,j,1:(veh_ind(1)-1),:)= hhcurrveh(i,j,1:(veh_ind(1)-1),:);
            end
            if NUM_VEH_OWNED(j,i+1)==0 % updating age of the oldest vehicle
                IND_AGE_OLDEST_VEH(j,i+1)=0;
            else
                IND_AGE_OLDEST_VEH(j,i+1)=2017+i-min(hhcurrveh(i+1,j,1:NUM_VEH_OWNED(j,i+1),1));
            end

            IND_AVG_VEH_HOLD_TIME(j,i+1)=sum(hhsoldveh(i+1,j,:,1)-hhsoldveh(i+1,j,:,2))/TOT_VEH_SOLD(j,i+1);
            NUM_VEH_SOLD(j,i+1) =length(find(hhsoldveh(i+1,j,:,1)>=2016+i-10));
            if NUM_VEH_SOLD(j,i+1)>0
                SOLD_VEH_IND(j,i+1)=1;
            else
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            SOLD_VEH_IND(j,i+1)=0;
        end

    elseif TRANSACTION(j,i) == 3
        TOT_VEH_SOLD(j,i+1)= TOT_VEH_SOLD(j,i);
        hhsoldveh(i+1,j,:,:)=hhsoldveh(i,j,:,:);
        NUM_VEH_SOLD(j,i+1) =length(find(hhsoldveh(i+1,j,:,1)>=2016+i-10));
        if NUM_VEH_SOLD(j,i+1)>0
            SOLD_VEH_IND(j,i+1)=1;
        else
            SOLD_VEH_IND(j,i+1)=0;
        end
        IND_AVG_VEH_HOLD_TIME(j,i+1)=IND_AVG_VEH_HOLD_TIME(j,i);
        OWNED_VEH_IND(j,i+1)=1;
        hhcurrveh(i+1,j,1:NUM_VEH_OWNED(j,i),:)= hhcurrveh(i,j,1:NUM_VEH_OWNED(j,i),:);
        NUM_VEH_OWNED(j,i+1)= NUM_VEH_OWNED(j,i)+1;
        b=rand();
        if b < prob_BUYnotLEASE(j) % probability of buying new vehicle
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),3)=1;
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),2)=2016+i;
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),1)=2016+i;
            utilityDIESEL = ascDIESEL + betaDIESEL_MALE * MALE(:,1) + betaDIESEL_HHCHILDREN * HHCHILDREN(:,1) +
betaDIESEL_AGE * AGE(:,i) + betaDIESEL_HHSIZE * HHSIZE(:,1) + betaDIESEL_BACHELORS * BACHELORS(:,1) +
betaDIESEL_MARRIED * MARRIED(:,1) + betaDIESEL_VEH_PURCH_PROB * prob_Acquire(:,i) + betaDIESEL_GROCERY_DIST *
GROCERY_DIST(:,1) + betaDIESEL_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaDIESEL_WORKSCHOOL_DIST *
WORKSCHOOL_DIST(:,1) + betaDIESEL_NO_DISABILITY * NOT_DISABILED(:,1) + betaDIESEL_DA_TO_WORK *
DA_TO_WORK(:,1);
            utilityHEV = ascHEV + betaHEV_MALE * MALE(:,1) + betaHEV_HHCHILDREN * HHCHILDREN(:,1) + betaHEV_AGE *
AGE(:,i) + betaHEV_HHSIZE * HHSIZE(:,1) + betaHEV_BACHELORS * BACHELORS(:,1) + betaHEV_MARRIED * MARRIED(:,1) +
betaHEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaHEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaHEV_TRANSIT_DIST *
TRANSIT_DIST(:,1) + betaHEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaHEV_NO_DISABILITY *
NOT_DISABILED(:,1) + betaHEV_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityPHEV = ascPHEV + betaPHEV_MALE * MALE(:,1) + betaPHEV_HHCHILDREN * HHCHILDREN(:,1) + betaPHEV_AGE *
AGE(:,i) + betaPHEV_HHSIZE * HHSIZE(:,1) + betaPHEV_BACHELORS * BACHELORS(:,1) + betaPHEV_MARRIED * MARRIED(:,1) +
betaPHEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaPHEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaPHEV_TRANSIT_DIST
* TRANSIT_DIST(:,1) + betaPHEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaPHEV_NO_DISABILITY *
NOT_DISABILED(:,1) + betaPHEV_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityBEV = ascBEV + betaBEV_MALE * MALE(:,1) + betaBEV_HHCHILDREN * HHCHILDREN(:,1) + betaBEV_AGE *
AGE(:,i) + betaBEV_HHSIZE * HHSIZE(:,1) + betaBEV_BACHELORS * BACHELORS(:,1) + betaBEV_MARRIED * MARRIED(:,1) +
betaBEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaBEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaBEV_TRANSIT_DIST *
TRANSIT_DIST(:,1) + betaBEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaBEV_NO_DISABILITY *
NOT_DISABILED(:,1) + betaBEV_DA_TO_WORK * DA_TO_WORK(:,1);
            SUM = 1+exp(utilityDIESEL(j))+exp(utilityHEV(j))+exp(utilityPHEV(j))+exp(utilityBEV(j));
            probDIESEL = exp(utilityDIESEL(j)) / SUM;
            probHEV = exp(utilityHEV(j)) / SUM;
            probPHEV = exp(utilityPHEV(j)) / SUM;
            probBEV = exp(utilityBEV(j)) / SUM;
            probGASOLINE = 1 - (probDIESEL + probHEV + probPHEV + probBEV);
            a=rand();
            if (a <= probDIESEL)
                hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),5)=1;
            elseif (a <= probDIESEL + probHEV)
                hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),6)=1;
            elseif (a <= probDIESEL + probHEV + probPHEV)
                hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),7)=1;
            elseif (a <= probDIESEL + probHEV + probPHEV + probBEV)
                hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),8)=1;
            else
                hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),4)=1;
            end

            WTPa = ascWTPA + betaWTPA_AGE * AGE(:,1) + betaWTPA_HHWORKERS * HHWORKERS(:,1) + betaWTPA_HHINCOME *
HHINCOME(:,1) + betaWTPA_WHITE * WHITE(:,1) + betaWTPA_BACHELORS * BACHELORS(:,1) + betaWTPA_FULL_TIME *
FULL_TIME(:,1) + betaWTPA_UNEMPLOYED * UNEMPLOYED(:,1) + betaWTPA_MARRIED * MARRIED(:,1) +
betaWTPA_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaWTPA_VEH_PURCH_PROB * prob_Acquire(:,i); %WTP for AV first scenario
            WTPw = ascWTPW + betaWTPW_AGE * AGE(:,1) + betaWTPW_HHCHILDREN * HHCHILDREN(:,1) +
betaWTPW_HHINCOME * HHINCOME(:,1) + betaWTPW_STUDENT * STUDENT(:,1) + betaWTPW_UNEMPLOYED *
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UNEMPLOYED(:,1) + betaWTPW_MARRIED * MARRIED(:,1) + betaWTPW_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaWTPW_VEH_PURCH_PROB * prob_Acquire(:,i) + betaWTPW_GROCERY_DIST * GROCERY_DIST(:,1) + betaWTPW_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaWTPW_NO_DISABILITY * NOT_DISABILED(:,1); %WTP for AV with HV option
            WTPo = ascWTPO + betaWTPO_MALE * MALE(:,1) + betaWTPO_AGE * AGE(:,i) + betaWTPO_HHCHILDREN * HHCHILDREN(:,1) + betaWTPO_WHITE * WHITE(:,1) + betaWTPO_BACHELORS * BACHELORS(:,1) + betaWTPO_UNEMPLOYED * UNEMPLOYED(:,1) + betaWTPO_MARRIED + MARRIED(:,1) + betaWTPO_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaWTPO_VEH_PURCH_PROB * prob_Acquire(:,i) + betaWTPO_GROCERY_DIST * GROCERY_DIST(:,1) + betaWTPO_DOWNTOWN_DIST * DTdist(:,i) + betaWTPO_NO_DISABILITY * NOT_DISABILED(:,1); %WTP for AV without HV option
            WTP(i,j,13) = WTPw(j);  % **CHANGE THIS ROW AND THREE OTHER PLACES IN CODE TO SWITCH WTP SCENARIO**

            WTP(i,j,13) = (1 + sqrt(i/4))*WTP(i,j,13);

            if (WTP(i,j,13))>=techprice(1,i)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),16)=1;
            else
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),16)=0;
            end

          else
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),3)=0;
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),2)=2016+i;
            %People buy on an average 6.18 year old vehicle and standard deviation is 5.48 years (given they buy old vehicle).
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),1)=round(2016+i-6.18+ (-1+2*rand())*5.48);
            utilityDIESEL = ascDIESEL + betaDIESEL_MALE * MALE(:,1) + betaDIESEL_HHCHILDREN * HHCHILDREN(:,1) + betaDIESEL_AGE * AGE(:,i) + betaDIESEL_HHSIZE * HHSIZE(:,1) + betaDIESEL_BACHELORS * BACHELORS(:,1) + betaDIESEL_MARRIED * MARRIED(:,1) + betaDIESEL_VEH_PURCH_PROB * prob_Acquire(:,i) + betaDIESEL_GROCERY_DIST * GROCERY_DIST(:,1) + betaDIESEL_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaDIESEL_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaDIESEL_NO_DISABILITY * NOT_DISABILED(:,1) + betaDIESEL_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityHEV = ascHEV + betaHEV_MALE * MALE(:,1) + betaHEV_HHCHILDREN * HHCHILDREN(:,1) + betaHEV_AGE * AGE(:,i) + betaHEV_HHSIZE * HHSIZE(:,1) + betaHEV_BACHELORS * BACHELORS(:,1) + betaHEV_MARRIED * MARRIED(:,1) + betaHEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaHEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaHEV_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaHEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaHEV_NO_DISABILITY * NOT_DISABILED(:,1) + betaHEV_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityPHEV = ascPHEV + betaPHEV_MALE * MALE(:,1) + betaPHEV_HHCHILDREN * HHCHILDREN(:,1) + betaPHEV_AGE * AGE(:,i) + betaPHEV_HHSIZE * HHSIZE(:,1) + betaPHEV_BACHELORS * BACHELORS(:,1) + betaPHEV_MARRIED * MARRIED(:,1) + betaPHEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaPHEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaPHEV_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaPHEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaPHEV_NO_DISABILITY * NOT_DISABILED(:,1) + betaPHEV_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityBEV = ascBEV + betaBEV_MALE * MALE(:,1) + betaBEV_HHCHILDREN * HHCHILDREN(:,1) + betaBEV_AGE * AGE(:,i) + betaBEV_HHSIZE * HHSIZE(:,1) + betaBEV_BACHELORS * BACHELORS(:,1) + betaBEV_MARRIED * MARRIED(:,1) + betaBEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaBEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaBEV_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaBEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaBEV_NO_DISABILITY * NOT_DISABILED(:,1) + betaBEV_DA_TO_WORK * DA_TO_WORK(:,1);
            SUM = 1+exp(utilityDIESEL(j))+exp(utilityHEV(j))+exp(utilityPHEV(j))+exp(utilityBEV(j));
            probDIESEL = exp(utilityDIESEL(j)) / SUM;
            probHEV = exp(utilityHEV(j)) / SUM;
            probPHEV = exp(utilityPHEV(j)) / SUM;
            probBEV = exp(utilityBEV(j)) / SUM;
            probGASOLINE = 1 - (probDIESEL + probHEV + probPHEV + probBEV);
            a=rand();
            if (a <= probDIESEL)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),5)=1;
            elseif (a <= probDIESEL + probHEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),6)=1;
            elseif (a <= probDIESEL + probHEV + probPHEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),7)=1;
            elseif (a <= probDIESEL + probHEV + probPHEV + probBEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),8)=1;
            else
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),4)=1;
            end

            WTPa = ascWTPA + betaWTPA_AGE * AGE(:,i) + betaWTPA_HHWORKERS * HHWORKERS(:,1) + betaWTPA_HHINCOME * HHINCOME(:,1) + betaWTPA_WHITE * WHITE(:,1) + betaWTPA_BACHELORS * BACHELORS(:,1) + betaWTPA_FULL_TIME *
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FULL_TIME(:,1) + betaWTPA_UNEMPLOYED * UNEMPLOYED(:,1) + betaWTPA_MARRIED * MARRIED(:,1) +
betaWTPA_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaWTPA_VEH_PURCH_PROB * prob_Acquire(:,i); %WTP for AV first scenario
            WTPw = ascWTPW + betaWTPW_AGE * AGE(:,i) + betaWTPW_HHCHILDREN * HHCHILDREN(:,1) +
betaWTPW_HHINCOME * HHINCOME(:,1) + betaWTPW_STUDENT * STUDENT(:,1) + betaWTPW_UNEMPLOYED *
UNEMPLOYED(:,1) + betaWTPW_MARRIED * MARRIED(:,1) + betaWTPW_HHVEHICLES * NUM_VEH_OWNED(:,i) +
betaWTPW_VEH_PURCH_PROB * prob_Acquire(:,i) + betaWTPW_GROCERY_DIST * GROCERY_DIST(:,1) +
betaWTPW_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaWTPW_NO_DISABILITY * NOT_DISABILED(:,1); %WTP for AV with HV
option
            WTPo = ascWTPO + betaWTPO_MALE * MALE(:,1) + betaWTPO_AGE * AGE(:,i) + betaWTPO_HHCHILDREN *
HHCHILDREN(:,1) + betaWTPO_WHITE * WHITE(:,1) + betaWTPO_BACHELORS * BACHELORS(:,1) + betaWTPO_UNEMPLOYED *
UNEMPLOYED(:,1) + betaWTPO_MARRIED + MARRIED(:,1) + betaWTPO_HHVEHICLES * NUM_VEH_OWNED(:,i) +
betaWTPO_VEH_PURCH_PROB * prob_Acquire(:,i) + betaWTPO_GROCERY_DIST * GROCERY_DIST(:,1) +
betaWTPO_DOWNTOWN_DIST * DTdist(:,i) + betaWTPO_NO_DISABILITY * NOT_DISABILED(:,1); %WTP for AV without HV option
            WTP(i,j,13) = WTPw(j);  % **CHANGE THIS ROW AND THREE OTHER PLACES IN CODE TO SWITCH WTP SCENARIO**

            WTP(i,j,13) = (1 + sqrt(i/4))*WTP(i,j,13);

            if (WTP(i,j,13))>=techprice(1,i)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),16)=1;
            else
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),16)=0;
            end

        end
        IND_AGE_OLDEST_VEH(j,i+1)=2017+i-min(hhcurrveh(i+1,j,1:NUM_VEH_OWNED(j,i+1),1));

      elseif TRANSACTION(j,i) == 2
        TOT_VEH_SOLD(j,i+1)= TOT_VEH_SOLD(j,i)+1;
        veh_ind = find(hhcurrveh(i,j,1:NUM_VEH_OWNED(j,i),1)==min(hhcurrveh(i,j,1:NUM_VEH_OWNED(j,i),1)));
        hhsoldveh(i+1,j,1:TOT_VEH_SOLD(j,i),:)=hhsoldveh(i,j,1:TOT_VEH_SOLD(j,i),:);
        hhsoldveh(i+1,j,TOT_VEH_SOLD(j,i+1),:)=hhcurrveh(i,j,veh_ind(1),:);
        hhsoldveh(i+1,j,TOT_VEH_SOLD(j,i+1),1)=2016+i; % updating selling year of sold vehicle and adding it to sold vehicles
        NUM_VEH_SOLD(j,i+1) =length(find(hhsoldveh(i+1,j,:,1)>=2016+i-10));
        if NUM_VEH_SOLD(j,i+1)>0
          SOLD_VEH_IND(j,i+1)=1;
        else
          SOLD_VEH_IND(j,i+1)=0;
        end
        IND_AVG_VEH_HOLD_TIME(j,i+1)=sum(hhsoldveh(i+1,j,:,1)-hhsoldveh(i+1,j,:,2))/TOT_VEH_SOLD(j,i+1);
        OWNED_VEH_IND(j,i+1)= OWNED_VEH_IND(j,i);
        if veh_ind(1) <  NUM_VEH_OWNED(j,i)  % updating current vehicle inventory
          hhcurrveh(i+1,j,1:(veh_ind(1)-1),:)= hhcurrveh(i,j,1:(veh_ind(1)-1),:);
          hhcurrveh(i+1,j,veh_ind(1):(NUM_VEH_OWNED(j,i)-1),:)= hhcurrveh(i,j,(veh_ind(1)+1):NUM_VEH_OWNED(j,i),:);
        elseif NUM_VEH_OWNED(j,i)==1
          hhcurrveh(i+1,j,1,:)= zeros(16,1);
        else
          hhcurrveh(i+1,j,1:(veh_ind(1)-1),:)= hhcurrveh(i,j,1:(veh_ind(1)-1),:);
        end

        NUM_VEH_OWNED(j,i+1)= NUM_VEH_OWNED(j,i);
        b=rand();
        if b < prob_BUYnotLEASE(j) % probability of buying new vehicle
          hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),3)=1;
          hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),2)=2016+i;
          hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),1)=2016+i;
          utilityDIESEL = ascDIESEL + betaDIESEL_MALE * MALE(:,1) + betaDIESEL_HHCHILDREN * HHCHILDREN(:,1) +
betaDIESEL_AGE * AGE(:,i) + betaDIESEL_HHSIZE * HHSIZE(:,1) + betaDIESEL_BACHELORS * BACHELORS(:,1) +
betaDIESEL_MARRIED * MARRIED(:,1) + betaDIESEL_VEH_PURCH_PROB * prob_Acquire(:,i) + betaDIESEL_GROCERY_DIST *
GROCERY_DIST(:,1) + betaDIESEL_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaDIESEL_WORKSCHOOL_DIST *
WORKSCHOOL_DIST(:,1) + betaDIESEL_NO_DISABILITY * NOT_DISABILED(:,1) + betaDIESEL_DA_TO_WORK *
DA_TO_WORK(:,1);
          utilityHEV = ascHEV + betaHEV_MALE * MALE(:,1) + betaHEV_HHCHILDREN * HHCHILDREN(:,1) + betaHEV_AGE *
AGE(:,i) + betaHEV_HHSIZE * HHSIZE(:,1) + betaHEV_BACHELORS * BACHELORS(:,1) + betaHEV_MARRIED * MARRIED(:,1) +
betaHEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaHEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaHEV_TRANSIT_DIST *
TRANSIT_DIST(:,1) + betaHEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaHEV_NO_DISABILITY *
NOT_DISABILED(:,1) + betaHEV_DA_TO_WORK * DA_TO_WORK(:,1);
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            utilityPHEV = ascPHEV + betaPHEV_MALE * MALE(:,1) + betaPHEV_HHCHILDREN * HHCHILDREN(:,1) + betaPHEV_AGE * AGE(:,i) + betaPHEV_HHSIZE * HHSIZE(:,1) + betaPHEV_BACHELORS * BACHELORS(:,1) + betaPHEV_MARRIED * MARRIED(:,1) + betaPHEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaPHEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaPHEV_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaPHEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaPHEV_NO_DISABILITY * NOT_DISABILED(:,1) + betaPHEV_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityBEV = ascBEV + betaBEV_MALE * MALE(:,1) + betaBEV_HHCHILDREN * HHCHILDREN(:,1) + betaBEV_AGE * AGE(:,i) + betaBEV_HHSIZE * HHSIZE(:,1) + betaBEV_BACHELORS * BACHELORS(:,1) + betaBEV_MARRIED * MARRIED(:,1) + betaBEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaBEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaBEV_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaBEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaBEV_NO_DISABILITY * NOT_DISABILED(:,1) + betaBEV_DA_TO_WORK * DA_TO_WORK(:,1);
            SUM = 1+exp(utilityDIESEL(j))+exp(utilityHEV(j))+exp(utilityPHEV(j))+exp(utilityBEV(j));
            probDIESEL = exp(utilityDIESEL(j)) / SUM;
            probHEV = exp(utilityHEV(j)) / SUM;
            probPHEV = exp(utilityPHEV(j)) / SUM;
            probBEV = exp(utilityBEV(j)) / SUM;
            probGASOLINE = 1 - (probDIESEL + probHEV + probPHEV + probBEV);
            a=rand();
            if (a <= probDIESEL)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),5)=1;
            elseif (a <= probDIESEL + probHEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),6)=1;
            elseif (a <= probDIESEL + probHEV + probPHEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),7)=1;
            elseif (a <= probDIESEL + probHEV + probPHEV + probBEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),8)=1;
            else
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),4)=1;
            end

            WTPa = ascWTPA + betaWTPA_AGE * AGE(:,i) + betaWTPA_HHWORKERS * HHWORKERS(:,1) + betaWTPA_HHINCOME * HHINCOME(:,1) + betaWTPA_WHITE * WHITE(:,1) + betaWTPA_BACHELORS * BACHELORS(:,1) + betaWTPA_FULL_TIME * FULL_TIME(:,1) + betaWTPA_UNEMPLOYED * UNEMPLOYED(:,1) + betaWTPA_MARRIED * MARRIED(:,1) + betaWTPA_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaWTPA_VEH_PURCH_PROB * prob_Acquire(:,i); %WTP for AV first scenario
            WTPw = ascWTPW + betaWTPW_AGE * AGE(:,i) + betaWTPW_HHCHILDREN * HHCHILDREN(:,1) + betaWTPW_HHINCOME * HHINCOME(:,1) + betaWTPW_STUDENT * STUDENT(:,1) + betaWTPW_UNEMPLOYED * UNEMPLOYED(:,1) + betaWTPW_MARRIED * MARRIED(:,1) + betaWTPW_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaWTPW_VEH_PURCH_PROB * prob_Acquire(:,i) + betaWTPW_GROCERY_DIST * GROCERY_DIST(:,1) + betaWTPW_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaWTPW_NO_DISABILITY * NOT_DISABILED(:,1); %WTP for AV with HV option
            WTPo = ascWTPO + betaWTPO_MALE * MALE(:,1) + betaWTPO_AGE * AGE(:,i) + betaWTPO_HHCHILDREN * HHCHILDREN(:,1) + betaWTPO_WHITE * WHITE(:,1) + betaWTPO_BACHELORS * BACHELORS(:,1) + betaWTPO_UNEMPLOYED * UNEMPLOYED(:,1) + betaWTPO_MARRIED + MARRIED(:,1) + betaWTPO_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaWTPO_VEH_PURCH_PROB * prob_Acquire(:,i) + betaWTPO_GROCERY_DIST * GROCERY_DIST(:,1) + betaWTPO_DOWNTOWN_DIST * DTdist(:,i) + betaWTPO_NO_DISABILITY * NOT_DISABILED(:,1); %WTP for AV without HV option
            WTP(i,j,13) = WTPw(j);  % **CHANGE THIS ROW AND THREE OTHER PLACES IN CODE TO SWITCH WTP SCENARIO**

            WTP(i,j,13) = (1 + sqrt(i/4))*WTP(i,j,13);

            if (WTP(i,j,13))>=techprice(1,i)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),16)=1;
            else
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),16)=0;
            end

          else
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),3)=0;
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),2)=2016+i;
            %People buy on an average 6.18 year old vehicle and standard deviation is 5.48 years (given they buy old vehicle).
            hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),1)=round(2016+i-6.18+ (-1+2*rand())*5.48);
            utilityDIESEL = ascDIESEL + betaDIESEL_MALE * MALE(:,1) + betaDIESEL_HHCHILDREN * HHCHILDREN(:,1) + betaDIESEL_AGE * AGE(:,i) + betaDIESEL_HHSIZE * HHSIZE(:,1) + betaDIESEL_BACHELORS * BACHELORS(:,1) + betaDIESEL_MARRIED * MARRIED(:,1) + betaDIESEL_VEH_PURCH_PROB * prob_Acquire(:,i) + betaDIESEL_GROCERY_DIST * GROCERY_DIST(:,1) + betaDIESEL_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaDIESEL_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaDIESEL_NO_DISABILITY * NOT_DISABILED(:,1) + betaDIESEL_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityHEV = ascHEV + betaHEV_MALE * MALE(:,1) + betaHEV_HHCHILDREN * HHCHILDREN(:,1) + betaHEV_AGE * AGE(:,i) + betaHEV_HHSIZE * HHSIZE(:,1) + betaHEV_BACHELORS * BACHELORS(:,1) + betaHEV_MARRIED * MARRIED(:,1) +
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betaHEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaHEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaHEV_TRANSIT_DIST *
TRANSIT_DIST(:,1) + betaHEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaHEV_NO_DISABILITY *
NOT_DISABILED(:,1) + betaHEV_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityPHEV = ascPHEV + betaPHEV_MALE * MALE(:,1) + betaPHEV_HHCHILDREN * HHCHILDREN(:,1) + betaPHEV_AGE *
AGE(:,i) + betaPHEV_HHSIZE * HHSIZE(:,1) + betaPHEV_BACHELORS * BACHELORS(:,1) + betaPHEV_MARRIED * MARRIED(:,1) +
betaPHEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaPHEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaPHEV_TRANSIT_DIST
* TRANSIT_DIST(:,1) + betaPHEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaPHEV_NO_DISABILITY *
NOT_DISABILED(:,1) + betaPHEV_DA_TO_WORK * DA_TO_WORK(:,1);
            utilityBEV = ascBEV + betaBEV_MALE * MALE(:,1) + betaBEV_HHCHILDREN * HHCHILDREN(:,1) + betaBEV_AGE *
AGE(:,i) + betaBEV_HHSIZE * HHSIZE(:,1) + betaBEV_BACHELORS * BACHELORS(:,1) + betaBEV_MARRIED * MARRIED(:,1) +
betaBEV_VEH_PURCH_PROB * prob_Acquire(:,i) + betaBEV_GROCERY_DIST * GROCERY_DIST(:,1) + betaBEV_TRANSIT_DIST *
TRANSIT_DIST(:,1) + betaBEV_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) + betaBEV_NO_DISABILITY *
NOT_DISABILED(:,1) + betaBEV_DA_TO_WORK * DA_TO_WORK(:,1);
            SUM = 1+exp(utilityDIESEL(j))+exp(utilityHEV(j))+exp(utilityPHEV(j))+exp(utilityBEV(j));
            probDIESEL = exp(utilityDIESEL(j)) / SUM;
            probHEV = exp(utilityHEV(j)) / SUM;
            probPHEV = exp(utilityPHEV(j)) / SUM;
            probBEV = exp(utilityBEV(j)) / SUM;
            probGASOLINE = 1 - (probDIESEL + probHEV + probPHEV + probBEV);
            a=rand();
            if (a <= probDIESEL)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),5)=1;
            elseif (a <= probDIESEL + probHEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),6)=1;
            elseif (a <= probDIESEL + probHEV + probPHEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),7)=1;
            elseif (a <= probDIESEL + probHEV + probPHEV + probBEV)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),8)=1;
            else
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),4)=1;
            end

            WTPa = ascWTPA + betaWTPA_AGE * AGE(:,i) + betaWTPA_HHWORKERS * HHWORKERS(:,1) + betaWTPA_HHINCOME *
HHINCOME(:,1) + betaWTPA_WHITE * WHITE(:,1) + betaWTPA_BACHELORS * BACHELORS(:,1) + betaWTPA_FULL_TIME *
FULL_TIME(:,1) + betaWTPA_UNEMPLOYED * UNEMPLOYED(:,1) + betaWTPA_MARRIED * MARRIED(:,1) +
betaWTPA_HHVEHICLES * NUM_VEH_OWNED(:,i) + betaWTPA_VEH_PURCH_PROB * prob_Acquire(:,i); %WTP for AV first scenario
            WTPw = ascWTPW + betaWTPW_AGE * AGE(:,i) + betaWTPW_HHCHILDREN * HHCHILDREN(:,1) +
betaWTPW_HHINCOME * HHINCOME(:,1) + betaWTPW_STUDENT * STUDENT(:,1) + betaWTPW_UNEMPLOYED *
UNEMPLOYED(:,1) + betaWTPW_MARRIED * MARRIED(:,1) + betaWTPW_HHVEHICLES * NUM_VEH_OWNED(:,i) +
betaWTPW_VEH_PURCH_PROB * prob_Acquire(:,i) + betaWTPW_GROCERY_DIST * GROCERY_DIST(:,1) +
betaWTPW_TRANSIT_DIST * TRANSIT_DIST(:,1) + betaWTPW_NO_DISABILITY * NOT_DISABILED(:,1); %WTP for AV with HV
option
            WTPo = ascWTPO + betaWTPO_MALE * MALE(:,1) + betaWTPO_AGE * AGE(:,i) + betaWTPO_HHCHILDREN *
HHCHILDREN(:,1) + betaWTPO_WHITE * WHITE(:,1) + betaWTPO_BACHELORS * BACHELORS(:,1) + betaWTPO_UNEMPLOYED *
UNEMPLOYED(:,1) + betaWTPO_MARRIED + MARRIED(:,1) + betaWTPO_HHVEHICLES * NUM_VEH_OWNED(:,i) +
betaWTPO_VEH_PURCH_PROB * prob_Acquire(:,i) + betaWTPO_GROCERY_DIST * GROCERY_DIST(:,1) +
betaWTPO_DOWNTOWN_DIST * DTdist(:,i) + betaWTPO_NO_DISABILITY * NOT_DISABILED(:,1); %WTP for AV without HV option
            WTP(i,j,13) = WTPw(j);  % **CHANGE THIS ROW AND THREE OTHER PLACES IN CODE TO SWITCH WTP SCENARIO**

            WTP(i,j,13) = (1 + sqrt(i/4))*WTP(i,j,13);

            if (WTP(i,j,13))>=techprice(1,i)
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),16)=1;
            else
              hhcurrveh(i+1,j,NUM_VEH_OWNED(j,i+1),16)=0;
            end
          end

          IND_AGE_OLDEST_VEH(j,i+1)=2017+i-min(hhcurrveh(i+1,j,1:NUM_VEH_OWNED(j,i+1),1));
      end
   end
   % Moving
   utilityMOVING = betaMOVE_MALE* MALE(:,1) + betaMOVE_AGE * AGE(:,i) + betaMOVE_HHCHILDREN * HHCHILDREN(:,1) +
betaMOVE_HHSIZE * HHSIZE(:,1) + betaMOVE_HHWORKERS * HHWORKERS(:,1) + betaMOVE_HHVEHICLES *
NUM_VEH_OWNED(:,i) + betaMOVE_VEH_PURCH_PROB * prob_Acquire(:,i) + betaMOVE_TRANSIT_DIST * TRANSIT_DIST(:,1) +
betaMOVE_NO_DISABILITY * NOT_DISABILED(:,1) + betaMOVE_DA_TO_WORK * DA_TO_WORK(:,1);
   ProbabilityMOVING = exp(utilityMOVING)./(ones(respon,1)+exp(utilityMOVING));
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    for j = 1:respon
        a = rand();
        if (a <= ProbabilityMOVING)
            utilityMoveDir = betaMOVEDIR_MALE * MALE(:,1) + betaMOVEDIR_HHCHILDREN * HHCHILDREN(:,1) +
betaMOVEDIR_HHSIZE * HHSIZE(:,1) + betaMOVEDIR_FULL_TIME * FULL_TIME(:,1) + betaMOVEDIR_PART_TIME *
PART_TIME(:,1) + betaMOVEDIR_STUDENT * STUDENT(:,1) + betaMOVEDIR_UNEMPLOYED * UNEMPLOYED(:,1) +
betaMOVEDIR_RETIRED * RETIRED(:,1) + betaMOVEDIR_HHVEHICLES * NUM_VEH_OWNED(:,i) +
betaMOVEDIR_VEH_PURCH_PROB * prob_Acquire(:,i) + betaMOVEDIR_WORKSCHOOL_DIST * WORKSCHOOL_DIST(:,1) +
betaMOVEDIR_NO_DISABILITY * NOT_DISABILED(:,1) + betaMOVEDIR_DA_TO_WORK * DA_TO_WORK(:,1);
            probTWOFAR = normcdf(hcutTWOFAR - utilityMoveDir(j));
            probONEFAR = normcdf(hcutONEFAR - utilityMoveDir(j)) - normcdf(hcutTWOFAR - utilityMoveDir(j));
            probSAME = normcdf(hcutSAME - utilityMoveDir(j)) - normcdf(hcutONEFAR - utilityMoveDir(j));
            probONECLOSE = normcdf(hcutONECLOSE - utilityMoveDir(j)) - normcdf(hcutSAME - utilityMoveDir(j));
            probTWOCLOSE = 1 - normcdf(hcutONECLOSE - utilityMoveDir(j));
            b = rand();
            if (b <= probTWOFAR)
                DTdist(j,i+1) = DTdist(j,i) * 1.5;
            elseif (b <= probTWOFAR + probONEFAR)
                DTdist(j,i+1) = DTdist(j,i) * 1.25;
            elseif (b <= probTWOFAR + probONEFAR + probSAME)
                DTdist(j,i+1) = DTdist(j,i);
            elseif (b <= probTWOFAR + probONEFAR + probSAME + probONECLOSE)
                DTdist(j,i+1) = DTdist(j,i) * 0.75;
            else
                DTdist(j,i+1) = DTdist(j,i) * 0.5;
            end
        else
            DTdist(j,i+1) = DTdist(j,i);
        end
    end

    for j=1:respon
        VMT(j,i) = ascVMT + betaVMT_MALE * MALE(j,1) + betaVMT_HHCHILDREN * HHCHILDREN(j,1) + betaVMT_WHITE *
WHITE(j,1) + betaVMT_FULL_TIME * FULL_TIME(j,1) + betaVMT_INCOME * HHINCOME(j,1) + betaVMT_PART_TIME *
PART_TIME(j,1) + betaVMT_RETIRED * RETIRED(j,1) + betaVMT_MARRIED * MARRIED(j,1) + betaVMT_LICENSE * LICENSE(j,1) +
betaVMT_HHVEHICLES * NUM_VEH_OWNED(j,i) + betaVMT_VEH_PURCH_YEAR_PROB * prob_Acquire(j,i) +
betaVMT_GROCERY_DIST * GROCERY_DIST(j,1) + betaVMT_WORKSCHOOL_DIST * WORKSCHOOL_DIST(j,1) +
betaVMT_DA_TO_WORK * DA_TO_WORK(j,1);
        if (NUM_VEH_OWNED(j,i) == 0) && (i < 4)
            VMT(j,i) = 0;
        end
        VMT_YEAR(i) = VMT_YEAR(i)+VMT(j,i);
        if i >= 4
            VMTpsav(j,i) = VMT(j,i) * percent_PrivSAV(j,i);
            VMTpsavYEAR(i) = VMTpsavYEAR(i)+VMTpsav(j,i);
            VMTdrs(j,i) = VMT(j,i) * percent_DRS(j,i);
            VMTdrsYEAR(i) = VMTdrsYEAR(i)+VMTdrs(j,i);
            if NUM_VEH_OWNED(j,i) == 0
                VMT(j,i) = VMTpsav(j,i) + VMTdrs(j,i);
            end
        else
            VMTpsav(j,i) = 0;
            VMTpsavYEAR(i) = 0;
            VMTdrs(j,i) = 0;
            VMTdrsYEAR(i) = 0;
        end
        VMT_vehicles(j,i) = VMT(j,i) - (VMTpsav(j,i) + VMTdrs(j,i));
        VMT_vehiclesYEAR(i) = VMT_vehiclesYEAR(i)+VMT_vehicles(j,i);

        %nominal VMT per vehicle based on age, then correct proportionally to HH's VMT_vehicles, then calculate HH's VMT by type
        if NUM_VEH_OWNED(j,i) > 0
            for k=1:NUM_VEH_OWNED(j,i)
                Vage(j,k,i) = hhcurrveh(i,j,k,1)-(2016+i);
                VMTknom(j,k,i) = 0.3672131*(Vage(j,k,i)^3)-13.21949*(Vage(j,k,i)^2)-232.8491*Vage(j,k,i)+14476.36;
                VMTtnom(j,i) = VMTtnom(j,i)+VMTknom(j,k,i);
            end
            VMTrat(j,i) = VMT_vehicles(j,i)/VMTtnom(j,i);
```

```
            for k=1:NUM_VEH_OWNED(j,i)
                VMTk(j,k,i) = VMTknom(j,k,i)*VMTrat(j,i);
                if hhcurrveh(i,j,k,5)==1 && hhcurrveh(i,j,k,16)==1
                    VMTpAVdiesel(j,i) = VMTpAVdiesel(j,i)+VMTk(j,k,i);
                    VMTpAVdieselYEAR(i) = VMTpAVdieselYEAR(i)+VMTpAVdiesel(j,i);
                elseif hhcurrveh(i,j,k,4)==1 && hhcurrveh(i,j,k,16)==1
                    VMTpAVgas(j,i) = VMTpAVgas(j,i)+VMTk(j,k,i);
                    VMTpAVgasYEAR(i) = VMTpAVgasYEAR(i)+VMTpAVgas(j,i);
                elseif hhcurrveh(i,j,k,6)==1 && hhcurrveh(i,j,k,16)==1
                    VMTpAVhev(j,i) = VMTpAVhev(j,i)+VMTk(j,k,i);
                    VMTpAVhevYEAR(i) = VMTpAVhevYEAR(i)+VMTpAVhev(j,i);
                elseif hhcurrveh(i,j,k,7)==1 && hhcurrveh(i,j,k,16)==1
                    VMTpAVphev(j,i) = VMTpAVphev(j,i)+VMTk(j,k,i);
                    VMTpAVphevYEAR(i) = VMTpAVphevYEAR(i)+VMTpAVphev(j,i);
                elseif hhcurrveh(i,j,k,8)==1 && hhcurrveh(i,j,k,16)==1
                    VMTpAVbev(j,i) = VMTpAVbev(j,i)+VMTk(j,k,i);
                    VMTpAVbevYEAR(i) = VMTpAVbevYEAR(i)+VMTpAVbev(j,i);
                elseif hhcurrveh(i,j,k,5)==1 && hhcurrveh(i,j,k,16)~=1
                    VMThvDIESEL(j,i) = VMThvDIESEL(j,i)+VMTk(j,k,i);
                    VMThvDIESEL_YEAR(i) = VMThvDIESEL_YEAR(i)+VMThvDIESEL(j,i);
                elseif hhcurrveh(i,j,k,4)==1 && hhcurrveh(i,j,k,16)~=1
                    VMThvGAS(j,i) = VMThvGAS(j,i)+VMTk(j,k,i);
                    VMThvGAS_YEAR(i) = VMThvGAS_YEAR(i)+VMThvGAS(j,i);
                elseif hhcurrveh(i,j,k,6)==1 && hhcurrveh(i,j,k,16)~=1
                    VMThvHEV(j,i) = VMThvHEV(j,i)+VMTk(j,k,i);
                    VMThvHEV_YEAR(i) = VMThvHEV_YEAR(i)+VMThvHEV(j,i);
                elseif hhcurrveh(i,j,k,7)==1 && hhcurrveh(i,j,k,16)~=1
                    VMThvPHEV(j,i) = VMThvPHEV(j,i)+VMTk(j,k,i);
                    VMThvPHEV_YEAR(i) = VMThvPHEV_YEAR(i)+VMThvPHEV(j,i);
                elseif hhcurrveh(i,j,k,8)==1 && hhcurrveh(i,j,k,16)~=1
                    VMThvBEV(j,i) = VMThvBEV(j,i)+VMTk(j,k,i);
                    VMThvBEV_YEAR(i) = VMThvBEV_YEAR(i)+VMThvBEV(j,i);
                end
            end
        end
    end
end

save('OutputData.mat');

%To obtain output
set=[1 2 3 4 9 14 19 24 29 34]; % Outputs report values every 5 years
HHWEIGHT= input(:,62);

% number and percentage of vehicles with each powertrain type (WEIGHTED with HHWEIGHT)
num_diesel = zeros(size(set,2),1);
num_gas = zeros(size(set,2),1);
num_avdiesel = zeros(size(set,2),1);
num_avgas = zeros(size(set,2),1);
num_hev = zeros(size(set,2),1);
num_avhev = zeros(size(set,2),1);
num_phev = zeros(size(set,2),1);
num_avphev = zeros(size(set,2),1);
num_bev = zeros(size(set,2),1);
num_avbev = zeros(size(set,2),1);
num_veh = zeros(size(set,2),1);
vmt_out = zeros(size(set,2),2); %columns for aggregate, per capita
vmt_drsout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_psavout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_personalout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_avout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_hvout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_dieselout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_gasout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_hybridout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_phevout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_bevout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
```

```
vmt_AVdieselout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_AVgasout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_AVhybridout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_AVphevout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_AVbevout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_HVdieselout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_HVgasout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_HVhybridout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_HVphevout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
vmt_HVbevout = zeros(size(set,2),3); %columns for aggregate, % of total, per capita
dtdist_out = zeros(size(set,2),2); %cumulative distance, average

for out = 1:size(set,2)
  loop = set(out);
  for j = 1:respon
     vmt_out(out,1) = vmt_out(out,1) + VMT(j,loop)* HHWEIGHT(j);
     vmt_drsout(out,1) = vmt_drsout(out,1) + VMTdrs(j,loop)* HHWEIGHT(j);
     vmt_psavout(out,1) = vmt_psavout(out,1) + VMTpsav(j,loop)* HHWEIGHT(j);
     vmt_personalout(out,1) = vmt_personalout(out,1) + VMT_vehicles(j,loop)* HHWEIGHT(j);
     vmt_hvout(out,1) = vmt_hvout(out,1) + (VMThvDIESEL(j,loop) + VMThvGAS(j,loop) + VMThvHEV(j,loop) + VMThvPHEV(j,loop) +
VMThvBEV(j,loop))* HHWEIGHT(j);
     vmt_avout(out,1) = vmt_avout(out,1) + (VMTpAVdiesel(j,loop) + VMTpAVgas(j,loop) + VMTpAVhev(j,loop) + VMTpAVphev(j,loop) +
VMTpAVbev(j,loop))* HHWEIGHT(j);
     vmt_dieselout(out,1) = vmt_dieselout(out,1) + (VMThvDIESEL(j,loop) + VMTpAVdiesel(j,loop))* HHWEIGHT(j);
     vmt_gasout(out,1) = vmt_gasout(out,1) + (VMThvGAS(j,loop) + VMTpAVgas(j,loop))* HHWEIGHT(j);
     vmt_hybridout(out,1) = vmt_hybridout(out,1) + (VMThvHEV(j,loop) + VMTpAVhev(j,loop))* HHWEIGHT(j);
     vmt_phevout(out,1) = vmt_phevout(out,1) + (VMThvPHEV(j,loop) + VMTpAVphev(j,loop))* HHWEIGHT(j);
     vmt_bevout(out,1) = vmt_bevout(out,1) + (VMThvBEV(j,loop) + VMTpAVbev(j,loop))* HHWEIGHT(j);
     vmt_AVdieselout(out,1) = vmt_AVdieselout(out,1) + VMTpAVdiesel(j,loop)* HHWEIGHT(j);
     vmt_AVgasout(out,1) = vmt_AVgasout(out,1) + VMTpAVgas(j,loop)* HHWEIGHT(j);
     vmt_AVhybridout(out,1) = vmt_AVhybridout(out,1) + VMTpAVhev(j,loop)* HHWEIGHT(j);
     vmt_AVphevout(out,1) = vmt_AVphevout(out,1) + VMTpAVphev(j,loop)* HHWEIGHT(j);
     vmt_AVbevout(out,1) = vmt_AVbevout(out,1) + VMTpAVbev(j,loop)* HHWEIGHT(j);
     vmt_HVdieselout(out,1) = vmt_HVdieselout(out,1) + VMThvDIESEL(j,loop)* HHWEIGHT(j);
     vmt_HVgasout(out,1) = vmt_HVgasout(out,1) + VMThvGAS(j,loop)* HHWEIGHT(j);
     vmt_HVhybridout(out,1) = vmt_HVhybridout(out,1) + VMThvHEV(j,loop)* HHWEIGHT(j);
     vmt_HVphevout(out,1) = vmt_HVphevout(out,1) + VMThvPHEV(j,loop)* HHWEIGHT(j);
     vmt_HVbevout(out,1) = vmt_HVbevout(out,1) + VMThvBEV(j,loop)* HHWEIGHT(j);

     dtdist_out(out) = dtdist_out(out) + DTdist(j,loop);
     % Diesel Non-AV
     if(sum(squeeze(hhcurrveh(loop,j,:,5)==1 & hhcurrveh(loop,j,:,16) ~= 1))>= 1)
        num_diesel(out) = num_diesel(out) + sum(squeeze(hhcurrveh(loop,j,:,5)==1 & hhcurrveh(loop,j,:,16) ~= 1))*HHWEIGHT(j);
     end
     % Gasoline Non-AV
     if(sum(squeeze(hhcurrveh(loop,j,:,4)==1 & hhcurrveh(loop,j,:,16) ~= 1))>= 1)
          num_gas(out) = num_gas(out) + sum(squeeze(hhcurrveh(loop,j,:,4)==1 & hhcurrveh(loop,j,:,16) ~= 1))*HHWEIGHT(j);
     end
     % AVDiesel
     if(sum(squeeze(hhcurrveh(loop,j,:,5)==1 & hhcurrveh(loop,j,:,16) == 1))>= 1)
        num_avdiesel(out) = num_avdiesel(out) + sum(squeeze(hhcurrveh(loop,j,:,5)==1 & hhcurrveh(loop,j,:,16) == 1))*HHWEIGHT(j);
     end
     % AVGas
     if(sum(squeeze(hhcurrveh(loop,j,:,4)==1 & hhcurrveh(loop,j,:,16) == 1))>= 1)
        num_avgas(out) = num_avgas(out) + sum(squeeze(hhcurrveh(loop,j,:,4)==1 & hhcurrveh(loop,j,:,16) == 1))*HHWEIGHT(j);
     end
     % HEV Non-AV
     if(sum(squeeze(hhcurrveh(loop,j,:,6)==1 & hhcurrveh(loop,j,:,16) ~= 1))>= 1)
        num_hev(out) = num_hev(out) + sum(squeeze(hhcurrveh(loop,j,:,6)==1 & hhcurrveh(loop,j,:,16) ~= 1))*HHWEIGHT(j);
     end
     % AVHEV
     if(sum(squeeze(hhcurrveh(loop,j,:,6)==1 & hhcurrveh(loop,j,:,16) == 1))>= 1)
          num_avhev(out) = num_avhev(out) + sum(squeeze(hhcurrveh(loop,j,:,6)==1 & hhcurrveh(loop,j,:,16) == 1))*HHWEIGHT(j);
     end
     % PHEV Non-AV
     if(sum(squeeze(hhcurrveh(loop,j,:,7)==1 & hhcurrveh(loop,j,:,16) ~= 1))>= 1)
        num_phev(out) = num_phev(out) + sum(squeeze(hhcurrveh(loop,j,:,7)==1 & hhcurrveh(loop,j,:,16) ~= 1))*HHWEIGHT(j);
```

```
        end
        % AVPHEV
        if(sum(squeeze(hhcurrveh(loop,j,:,7)==1 & hhcurrveh(loop,j,:,16) == 1))>= 1)
           num_avphev(out) = num_avphev(out) + sum(squeeze(hhcurrveh(loop,j,:,7)==1 & hhcurrveh(loop,j,:,16) == 1))*HHWEIGHT(j);
        end
        % BEV Non-AV
        if(sum(squeeze(hhcurrveh(loop,j,:,8)==1 & hhcurrveh(loop,j,:,16) ~= 1))>= 1)
           num_bev(out) = num_bev(out) + sum(squeeze(hhcurrveh(loop,j,:,8)==1 & hhcurrveh(loop,j,:,16) ~= 1))*HHWEIGHT(j);
        end
        % AVBEV
        if(sum(squeeze(hhcurrveh(loop,j,:,8)==1 & hhcurrveh(loop,j,:,16) == 1))>= 1)
           num_avbev(out) = num_avbev(out) + sum(squeeze(hhcurrveh(loop,j,:,8)==1 & hhcurrveh(loop,j,:,16) == 1))*HHWEIGHT(j);
        end
     end
     vmt_out(out,2) = vmt_out(out,1)/respon;
     vmt_drsout(out,2) = vmt_drsout(out,1)/vmt_out(out,1);
     vmt_psavout(out,2) = vmt_psavout(out,1)/vmt_out(out,1);
     vmt_personalout(out,2) = vmt_personalout(out,1)/vmt_out(out,1);
     vmt_hvout(out,2) = vmt_hvout(out,1)/vmt_out(out,1);
     vmt_avout(out,2) = vmt_avout(out,1)/vmt_out(out,1);
     vmt_dieselout(out,2) = vmt_dieselout(out,1)/vmt_out(out,1);
     vmt_gasout(out,2) = vmt_gasout(out,1)/vmt_out(out,1);
     vmt_hybridout(out,2) = vmt_hybridout(out,1)/vmt_out(out,1);
     vmt_phevout(out,2) = vmt_phevout(out,1)/vmt_out(out,1);
     vmt_bevout(out,2) = vmt_bevout(out,1)/vmt_out(out,1);
     vmt_AVdieselout(out,2) = vmt_AVdieselout(out,1)/vmt_out(out,1);
     vmt_AVgasout(out,2) = vmt_AVgasout(out,1)/vmt_out(out,1);
     vmt_AVhybridout(out,2) = vmt_AVhybridout(out,1)/vmt_out(out,1);
     vmt_AVphevout(out,2) = vmt_AVphevout(out,1)/vmt_out(out,1);
     vmt_AVbevout(out,2) = vmt_AVbevout(out,1)/vmt_out(out,1);
     vmt_HVdieselout(out,2) = vmt_HVdieselout(out,1)/vmt_out(out,1);
     vmt_HVgasout(out,2) = vmt_HVgasout(out,1)/vmt_out(out,1);
     vmt_HVhybridout(out,2) = vmt_HVhybridout(out,1)/vmt_out(out,1);
     vmt_HVphevout(out,2) = vmt_HVphevout(out,1)/vmt_out(out,1);
     vmt_HVbevout(out,2) = vmt_HVbevout(out,1)/vmt_out(out,1);

     vmt_drsout(out,3) = vmt_drsout(out,1)/1426;
     vmt_psavout(out,3) = vmt_psavout(out,1)/1426;
     vmt_personalout(out,3) = vmt_personalout(out,1)/1426;
     vmt_hvout(out,3) = vmt_hvout(out,1)/1426;
     vmt_avout(out,3) = vmt_avout(out,1)/1426;
     vmt_dieselout(out,3) = vmt_dieselout(out,1)/1426;
     vmt_gasout(out,3) = vmt_gasout(out,1)/1426;
     vmt_hybridout(out,3) = vmt_hybridout(out,1)/1426;
     vmt_phevout(out,3) = vmt_phevout(out,1)/1426;
     vmt_bevout(out,3) = vmt_bevout(out,1)/1426;
     vmt_AVdieselout(out,3) = vmt_AVdieselout(out,1)/1426;
     vmt_AVgasout(out,3) = vmt_AVgasout(out,1)/1426;
     vmt_AVhybridout(out,3) = vmt_AVhybridout(out,1)/1426;
     vmt_AVphevout(out,3) = vmt_AVphevout(out,1)/1426;
     vmt_AVbevout(out,3) = vmt_AVbevout(out,1)/1426;
     vmt_HVdieselout(out,3) = vmt_HVdieselout(out,1)/1426;
     vmt_HVgasout(out,3) = vmt_HVgasout(out,1)/1426;
     vmt_HVhybridout(out,3) = vmt_HVhybridout(out,1)/1426;
     vmt_HVphevout(out,3) = vmt_HVphevout(out,1)/1426;
     vmt_HVbevout(out,3) = vmt_HVbevout(out,1)/1426;
     dtdist_out(out,2) = dtdist_out(out,1)/1426;
     %Total vehicle count

num_veh(out)=num_avdiesel(out)+num_diesel(out)+num_gas(out)+num_avgas(out)+num_hev(out)+num_avhev(out)+num_phev(out)+num_avp
hev(out)+num_bev(out)+num_avbev(out);
end

xlswrite('1num_hvdiesel',num_diesel);
xlswrite('1num_avdiesel',num_avdiesel);
xlswrite('1num_hvgas',num_gas);
xlswrite('1num_avgas',num_avgas);
```

```
xlswrite('1num_hvhev',num_hev);
xlswrite('1num_avhev',num_avhev);
xlswrite('1num_hvphev',num_phev);
xlswrite('1num_avphev',num_avphev);
xlswrite('1num_hvbev',num_bev);
xlswrite('1num_avbev',num_avbev);
xlswrite('1vmt',vmt_out);
xlswrite('1vmtDRS',vmt_drsout);
xlswrite('1vmtPSAV',vmt_psavout);
xlswrite('1vmtPERSONAL',vmt_personalout);
xlswrite('1vmtAV',vmt_avout);
xlswrite('1vmtHV',vmt_hvout);
xlswrite('1vmtDIESEL',vmt_dieselout);
xlswrite('1vmtGAS',vmt_gasout);
xlswrite('1vmtHYBRID',vmt_hybridout);
xlswrite('1vmtPHEV',vmt_phevout);
xlswrite('1vmtBEV',vmt_bevout);
xlswrite('1vmtAVdiesel',vmt_AVdieselout);
xlswrite('1vmtAVgas',vmt_AVgasout);
xlswrite('1vmtAVhybrid',vmt_AVhybridout);
xlswrite('1vmtAVphev',vmt_AVphevout);
xlswrite('1vmtAVbev',vmt_AVbevout);
xlswrite('1vmtHVdiesel',vmt_HVdieselout);
xlswrite('1vmtHVgas',vmt_HVgasout);
xlswrite('1vmtHVhybrid',vmt_HVhybridout);
xlswrite('1vmtHVphev',vmt_HVphevout);
xlswrite('1vmtHVbev',vmt_HVbevout);
xlswrite('1DT Distance',dtdist_out);
```

Appendix B: Key Survey Questions

Key Survey Questions:

Q7 How interested are you in owning or leasing a completely self-driving vehicle (assuming it is affordable for your household)?
- ❍ I am very interested in owning or leasing a self-driving vehicle. (21.3%)
- ❍ I am moderately interested in owning or leasing a self-driving vehicle. (19.0%)
- ❍ I am slightly interested in owning or leasing a self-driving vehicle. (23.5%)
- ❍ I am not interested in owning or leasing a self-driving vehicle. (36.2%)

Q13 What is the percent probability that your household will purchase or lease a vehicle in the next year?
______ % (Average = 35.3%)

Display This Question:
If When do you expect to purchase or lease your next vehicle? I do not expect to ever purchase or lease another vehicle Is Not Selected

Q17 Please select the vehicle class that best describes the vehicle you expect to get:
- ❍ Gasoline or diesel-powered sedan (35.9%)
- ❍ Gasoline or diesel-powered coupe or compact car (9.9%)
- ❍ Gasoline or diesel-powered minivan, SUV, or crossover utility vehicle (28.3%)
- ❍ Gasoline or diesel-powered pickup truck (8.4%)
- ❍ Hybrid-electric vehicle (not plug-in) (13.0%)
- ❍ Plug-in hybrid electric vehicle (2.1%)
- ❍ Fully electric vehicle (2.5%)

Q19 Total cost of ownership of electric vehicles is expected to fall to a level competitive with gasoline power in 5 to 10 years, depending on energy prices. Assume that the total cost of ownership (all financial costs associated with owning & operating a vehicle, including fuel) of each power type is equal. Also assume that a fully electric vehicle can be charged to its full 200 mile range in 6 hours. What power source would you get in your household's next vehicle? Note: Assume that any vehicle type is available with each power option. Also, differences in vehicles will still exist (Examples: charging time, availability of charging, range, etc.).
- ❍ Diesel engine (2.5%)
- ❍ Gasoline engine (53.9%)
- ❍ Hybrid-electric (not plug-in) (25.6%)
- ❍ Plug-in hybrid (8.0%)
- ❍ Fully electric (10.1%)

Q20 Assume that the total cost of ownership (all financial costs associated with owning & operating a vehicle, including fuel) of each power type is equal. Also assume that a fully electric vehicle can be charged to its full 200 mile range in 2 hours. What power source would you get in your household's next vehicle? Note: Assume that any vehicle type is available with each power option. Also, differences in vehicles will still exist (Examples: charging time, availability of charging, range, etc.).

- Diesel engine (3.0%)
- Gasoline engine (47.2%)
- Hybrid-electric (not plug-in) (24.7%)
- Plug-in hybrid (10.1%)
- Fully electric (15.0%)

Q21 Assume that the total cost of ownership (all financial costs associated with owning & operating a vehicle, including fuel) of each power type is equal. Also assume that a fully electric vehicle can be charged to its full 200 mile range in 30 minutes. What power source would you get in your household's next vehicle? Note: Assume that any vehicle type is available with each power option. Also, differences in vehicles will still exist (Examples: charging time, availability of charging, range, etc.).

- Diesel engine (2.7%)
- Gasoline engine (42.8%)
- Hybrid-electric (not plug-in) (20.6%)
- Plug-in hybrid (9.5%)
- Fully electric (24.4%)

Q22 If a fully electric vehicle were your primary vehicle, how would it influence your typical driving patterns?

- I think I would definitely drive more. (9.1%)
- I think I would probably drive more. (16.9%)
- I think I would drive the same amount/Don't know. (51.9%)
- I think I would probably drive less. (12.7%)
- I think I would definitely drive less. (9.3%)

Display This Question:

If If you had access to an electric vehicle as your primary vehicle, how would it influence your typ... I think I would definitely drive more Is Selected

Or If you had access to an electric vehicle as your primary vehicle, how would it influence your typ... I think I would probably drive more Is Selected

Q23 By what percentage do you think you would increase your driving miles if a fully electric vehicle were your primary vehicle?

______ % (Average = 45.8%)

Display This Question:

If If you had access to an electric vehicle as your primary vehicle, how would it influence your typ... I think I would probably drive less Is Selected

Or If you had access to an electric vehicle as your primary vehicle, how would it influence your typ... I think I would definitely drive less Is Selected

Q24 By what percentage do you think you would decrease your driving miles if a fully electric vehicle were your primary vehicle?

______ % (Average = 45.5%)

Q25 Do you have access to a place you could charge an electric vehicle at your home, or could you install one if you desired? Note: Some residences may not have parking space with close access to electricity. Please consider whether this applies to you before answering this question.

- Yes, I have access to, or could install a place to charge at home. (56.6%)
- No, I do not have access to, nor could I install a place to charge at home. (43.4%)

Q26 Do you have access to a place you could charge an electric vehicle at your place of work or school?

- Yes, I have access to charging at my place of work or school. (25.5%)
- No, I don't have access to charging at my place of work or school. (74.5%)
- I am not currently working or going to school, or I do so from home. (This recorded as an omitted response)

Display This Question:
If Do you have access to a place you could charge an electric vehicle at your home, or could you ins... No Is Selected
And Do you have access to a place you could charge an electric vehicle at your place of work? No Is Not Selected

Q27 Would you consider owning or leasing a fully electric vehicle despite not having a place to charge at home?

- I definitely would still consider owning or leasing a fully electric vehicle. (3.0%)
- I probably would still consider owning or leasing a fully electric vehicle. (6.9%)
- Not Sure (32.6%)
- I probably would not still consider owning or leasing a fully electric vehicle. (15.8%)
- I definitely would not still consider owning or leasing a fully electric vehicle. (41.8%)

Display This Question:
If Do you have access to an electric vehicle charging station at your home, or could you install one if you desired? Yes Is Selected
And Do you have access to an electric vehicle charging station at your place of work? No Is Selected

Q28 Would you consider owning or leasing a fully electric vehicle despite not having a place to charge at work?

- I definitely would still consider owning or leasing a fully electric vehicle. (20.2%)
- I probably would still consider owning or leasing a fully electric vehicle. (26.8%)
- Not Sure (21.0%)
- I probably would not still consider owning or leasing a fully electric vehicle. (17.3%)
- I definitely would not still consider owning or leasing a fully electric vehicle. (14.6%)

Display This Question:

If Do you have access to an electric vehicle charging station at your home, or could you install one if you desired? No Is Selected

And Do you have access to an electric vehicle charging station at your place of work? No Is Selected

Q29 Would you consider owning or leasing a fully electric vehicle despite not having a place to charge at home or at work?

- I definitely would still consider owning or leasing a fully electric vehicle. (0.9%)
- I probably would still consider owning or leasing a fully electric vehicle. (17.0%)
- Not Sure (16.7%)
- I probably would not still consider owning or leasing a fully electric vehicle. (21.8%)
- I definitely would not still consider owning or leasing a fully electric vehicle. (43.6%)

Q31 Which of the following is your primary means of travel for the following activities? (Please select one for each activity.)

	Walk (1)	Bicycle (2)	Drive Alone (3)	Drive with Others (4)	Public Transport (Including School Buses) (6)	Not applicable (0)
Work trips (either home to workplace or workplace to home) (1_work_trip)	3.1%	0.7%	52.0%	6.3%	3.5%	34.3%
School trips (to and from your own school or your child(ren)'s school when school is in session) (1_school_trip)	1.9%	1.1%	21.5%	7.6%	2.9%	65.1%
Shopping trips (1_shopping_trip)	1.8%	0.4%	59.1%	32.9%	4.3%	1.5%
Personal business trips (Examples: gym and doctor appointments) (1_personal_trip)	0.3%	0.9%	59.3%	10.4%	4.0%	25.2%
Social/recreational trips (Examples: dining out and visiting friends) (1_social_trips)	1.8%	0.6%	33.4%	53.8%	4.0%	6.3%
Other trips (Examples: daycare and computer repair) (1_other_trips)	0.5%	1.0%	57.6%	20.0%	3.6%	17.3%

Q32 Assume you have a 30 minute urban or suburban trip to drive alone, are you willing to pay $7.50 to have your car drive itself on this one-way trip, assuming route and vehicle remain unchanged?

- I definitely am willing to pay $7.50. (11.3%)
- I probably am willing to pay $7.50. (16.4%)
- Not Sure (20.7%)
- I probably am not willing to pay $7.50. (19.8%)
- I definitely am not willing to pay $7.50. (31.9%)

Display This Question:

If Assume you have a 30 minute urban or suburban trip to drive alone, would you be willing to pay $7... Probably No Is Selected

Or Assume you have a 30 minute urban or suburban trip to drive alone, would you be willing to pay $7... Definitely No Is Selected

Or Assume you have a 30 minute urban or suburban trip to drive alone, would you be willing to pay $7... Not Sure Is Selected

Q33 Assume you have a 30 minute urban or suburban trip to drive alone, are you willing to pay $5.00 to have your car drive itself on this one-way trip, assuming route and vehicle remain unchanged?

- I definitely am willing to pay $5. (1.5%)
- I probably am willing to pay $5. (13.1%)
- Not Sure (24.7%)
- I probably am not willing to pay $5. (23.0%)
- I definitely am not willing to pay $5. (37.8%)

Display This Question:

If Assume you have a 30 minute urban or suburban trip to drive alone, would you be willing to pay $7.50 to have your car drive itself on this one-way trip, assuming all else is equal? Definitely Yes Is Selected

Or Assume you have a 30 minute urban or suburban trip to drive alone, would you be willing to pay $7.50 to have your car drive itself on this one-way trip, assuming all else is equal? Probably Yes Is Selected

Q34 Assume you have a 30 minute urban or suburban trip to drive alone, are you willing to pay $10.00 to have your car drive itself on this one-way trip, assuming route and vehicle remain unchanged?

- I definitely am willing to pay $10. (20.4%)
- I probably am willing to pay $10. (35.7%)
- Not Sure (23.2%)
- I probably am not willing to pay $10. (17.0%)
- I definitely am not willing to pay $10. (3.7%)

Q35 Assuming you own a vehicle that can drive itself, do you believe you will usually put it in self-drive mode when you are making trips…. (Please check all that apply)?

- ❑ Less than 50 miles. (27.8%)
- ❑ Between 50 and 100 miles. (29.6%)
- ❑ Between 100 and 500 miles. (31.3%)
- ❑ Over 500 miles. (24.0%)
- ❑ I will not use the self-driving mode. (31.2%)

Q36 If you had a car that could operate in self-driving mode or human-driven mode, for what percentage of your travel distance in the vehicle would you have it in self-driving mode?
______ % (Average = 35.9%)

Q37 Assuming self-driving vehicles are available at the time of your next vehicle purchase, and in the body style you intend to purchase, would you prefer to purchase a self-driving or human-driven vehicle? Note: disregard any potential price premium for self-driving vehicles.
- I would prefer a self-driving vehicle. (32.4%)
- I would prefer a human-driven vehicle. (61.8%)
- I do not intend to ever purchase a vehicle. (5.8%)

Q38 It is possible that that the premium for self-driving (in all settings) technology in early years of availability will be around $7,000 for a purchase, or $200 for a monthly lease. If the technology is available at the time of your household's next vehicle purchase, will your household pay this premium on top of the vehicle's purchase price to have it equipped with self-driving technology?
- Yes, my household will be willing to pay an additional $7,000 for a purchase or $200 for a monthly lease. (23.2%)
- No, my household will not be willing to pay that much. (70.7%)
- My household does not ever intend to purchase a vehicle. (6.1%)

Display This Question:
If It is possible that that the premium for self-driving (in all settings) technology in early years... Yes, I would be willing to pay an additional $7,000 for a purchase or $200 for a monthly lease Is Not Selected

Q39 Technology prices are expected to fall over time. If your household's next vehicle purchase occurs when the self-driving technology premium is $5,000 for a purchase, or $140 for a monthly lease, will your household pay this premium on top of the vehicle's purchase price to have it equipped with self-driving technology.
- Yes, my household will be willing to pay an additional $5,000 for a purchase or $140 for a monthly lease. (10.1%)
- No, my household will not be willing to pay that much. (81.6%)
- My household does not ever intend to purchase a vehicle. (8.3%)

Display This Question:
If It is possible that that the premium for self-driving (in all settings) technology in early years... Yes, I would be willing to pay an additional $7,000 for a purchase or $200 for a monthly lease Is Not Selected
And Technology prices are expected to fall over time. If your next vehicle purchase occurs when the s... Yes, I would be willing to pay an additional $5,000 for a purchase or $140 for a monthly lease Is Not Selected

Q40 It is possible that the self-driving technology premium many years from now will be $2,000 for a purchase, or $60 for a monthly lease. If your household's next vehicle purchase happens to occur during this time, will your household pay this technology premium on top of the vehicle's purchase price to have your vehicle equipped with self-driving technology?

- ❍ Yes, my household will be willing to pay an additional $2,000 for a purchase or $60 for a monthly lease. (26.8%)
- ❍ No, my household will not be willing to pay that much. (63.8%)
- ❍ My household does not ever intend to purchase a vehicle. (9.4%)

Q41 What is the most you will be willing to pay above the current purchase price for your household's next vehicle to be fully self-driving, but have the option for human driving when desired?
______ Added price in dollars (Average = $3,116.57)

Q42 What is the most you will be willing to pay above the current purchase price for your household's next vehicle to be fully self-driving, and without an option for human driving?
______ Added price in dollars (Average = $2,202.02)

Display This Question:
If American experts believe that the premium for self-driving technology in early ears of availabili... Yes Is Selected
Or Technology prices are expected to fall over time. If your next vehicle purchase occurs when the s... Yes Is Selected
Or A reasonable expectation for the self-driving technology premium many years from now is $1000. If... Yes Is Selected

Q44 SECTION 2: SHARED SELF-DRIVING VEHICLES Shared self-driving vehicle fleets will provide a service similar to a driver-less taxi, but at a lower price. Using a shared self-driving vehicle allows the flexibility to not use the same vehicle or mode for all trips or all legs of a trip. With this in mind, how likely would you be to make the following choices if a shared self-driving vehicle fleet were available at a price that is affordable to you?

	Very likely (1)	Somewhat likely (2)	Neither likely nor unlikely (3)	Somewhat unlikely (4)	Very unlikely (5)
Go places, like downtown, more often than you would go with a personal vehicle, since you would not need to find parking and pay parking fees. (1)	❍ 14.7%	❍ 26.5%	❍ 16.6%	❍ 9.3%	❍ 32.9%
Use public transit for more trips, knowing that the shared vehicles are available for the return trip. For example, ride the bus to work, since the shared vehicles are available in case you have to stay late. (2)	❍ 7.3%	❍ 19.7%	❍ 20.5%	❍ 14.3%	❍ 38.3%
Use bikeshare or walk for more trips, with the option of riding the shared vehicles on the return trip. (3)	❍ 5.4%	❍ 17.1%	❍ 22.5%	❍ 13.8%	❍ 41.2%

Q45 If shared self-driving vehicles were available, what would be the highest price per mile at which you would use them regularly (at least once per week)?
______ $ (Average = $0.44)

Q46 In what situations would you use the shared vehicles? (Please select all that apply)
- ❑ To avoid parking fees. (38.9%)
- ❑ When personal vehicle is unavailable due to maintenance or repairs. (35.1%)
- ❑ For long trips. (23.0%)
- ❑ For short trips. (17.1%)
- ❑ As an alternative to driving (for example, after drinking alcohol). (32.8%)
- ❑ Other: (1.8%) ____________________
- ❑ I would not use the shared vehicles. (33.9%)

Q47 If shared self-driving vehicles were available at an average price of $0.50 per mile, how do you think it would change your household's vehicle ownership?
- ❍ I think my household would add one or more vehicles. (9.9%)
- ❍ I do not think it would affect my household's vehicle ownership. (76.1%)
- ❍ I think my household will decrease the number of vehicles it owns, but retain at least one vehicle. (11.7%)
- ❍ I think my household would get rid of all of its vehicles. (2.3%)

Q48 Assume you have a trip to take that requires you to drive in a mostly urban or suburban setting, but you have the option to pay to make your drive shorter. What is the maximum you are willing to pay to shorten your drive as described for each scenario below?
Driving Alone:
-To eliminate 30 minutes from a 1 hour drive: (Average = $4.10)
-To eliminate 1 hour from a 2 hour drive: (Average = $6.52)
When driving with 2 friends or family members:
-To eliminate 30 minutes from a 1 hour drive: (Average = $4.56)
-To eliminate 1 hour from a 2 hour drive: (Average = $7.04)

Q49 Assuming you have a 1 hour urban or suburban trip to drive alone, are you willing to pay $15 to have your car drive itself for this one-way trip, assuming route and vehicle remain unchanged?
- ❍ I definitely am willing to pay $15. (6.8%)
- ❍ I probably am willing to pay $15. (15.9%)
- ❍ Not Sure (22.6%)
- ❍ I probably am not willing to pay $15. (18.9%)
- ❍ I definitely am not willing to pay $15. (35.8%)

Display This Question:

If Assuming you have a 1 hour urban or suburban trip to drive alone, would you be willing to pay $15... Probably No Is Selected

Or Assuming you have a 1 hour urban or suburban trip to drive alone, would you be willing to pay $15... Definitely No Is Selected

Or Assuming you have a 1 hour urban or suburban trip to drive alone, would you be willing to pay $15... Not Sure Is Selected

Q50 Assuming you have a 1 hour urban or suburban trip to drive alone, are you willing to pay $10 to have your car drive itself for this one-way trip, assuming route and vehicle remain unchanged?

- I definitely am willing to pay $10. (0.7%)
- I probably am willing to pay $10. (13.6%)
- Not Sure (20.6%)
- I probably am not willing to pay $10. (21.1%)
- I definitely am not willing to pay $10. (43.9%)

Display This Question:

If Assuming you have a 1 hour urban or suburban trip to drive alone, would you be willing to pay $15 to have your car drive itself for this one-way trip, assuming all else is equal? Definitely Yes Is Selected

Or Assuming you have a 1 hour urban or suburban trip to drive alone, would you be willing to pay $15 to have your car drive itself for this one-way trip, assuming all else is equal? Probably Yes Is Selected

Q51 Assuming you have a 1 hour urban or suburban trip to drive alone, are you willing to pay $20 to have your car drive itself for this one-way trip, assuming route and vehicle remain unchanged?

- I definitely am willing to pay $20. (18.3%)
- I probably am willing to pay $20. (44.9%)
- Not Sure (22.1%)
- I probably am not willing to pay $20. (13.7%)
- I definitely am not willing to pay $20. (1.1%)

Q52 If shared self-driving vehicles are available, and can be ridden at a price of $2 per mile, with average pickup/response times of less than 5 minutes, which of the following transportation choices would your household be most likely to make?

- My household would not own a personal vehicle, and would rely primarily on the shared vehicles. (3.6%)
- My household would not own a personal vehicle, and would rely on a combination of the shared vehicles and other modes (for example, public transportation, bikeshare). (3.6%)
- My household would rely primarily on modes other than the shared vehicles or personal vehicles. (10.7%)
- My household would own one or more vehicles, but primarily use the shared vehicles. (7.5%)
- My household would primarily rely on one or more personal vehicles, but would use the shared vehicles some of the time. (29.3%)
- My household would rely primarily on personal vehicles, and would not use the shared vehicles. (44.5%)
- Other: (0.8%) ____________________

Q53 ...and what percentage of your travel distance do you expect would be via the shared self-driving vehicles at $2 per mile?

______ % (Average = 15.3%)

Q54 If shared self-driving vehicles are available, and can be ridden at a price of $1 per mile, with pickup/response times of less than 5 minutes, which of the following transportation choices would your household be most likely to make?

- My household would not own a personal vehicle, and would rely primarily on the shared vehicles. (4.3%)
- My household would not own a personal vehicle, and would rely on a combination of the shared vehicles and other modes (for example, public transportation, bikeshare). (3.7%)
- My household would rely primarily on modes other than the shared vehicles or personal vehicles. (9.2%)
- My household would own one or more vehicles, but primarily use the shared vehicles. (8.5%)
- My household would primarily rely on one or more personal vehicles, but would use the shared vehicles some of the time. (31.2%)
- My household would rely primarily on personal vehicles, and would not use the shared vehicles. (42.5%)
- Other: (0.7%) ____________________

Q55 ...and what percentage of your travel distance do you expect would be via the shared self-driving vehicles at $1 per mile?

______ % (Average = 18.6%)

Q56 If shared self-driving vehicles are available, and can be ridden at a price of $0.50 per mile, with pickup/response times of less than 5 minutes, which of the following transportation choices would your household be most likely to make?

- My household would not own a personal vehicle, and would rely primarily on the shared vehicles. (4.4%)
- My household would not own a personal vehicle, and would rely on a combination of the shared vehicles and other modes (for example, public transportation, bikeshare). (4.1%)
- My household would rely primarily on modes other than the shared vehicles or personal vehicles. (7.5%)
- My household would own one or more vehicles, but primarily use the shared vehicles. (12.5%)
- My household would primarily rely on one or more personal vehicles, but would use the shared vehicles some of the time. (32.4%)
- My household would rely primarily on personal vehicles, and would not use the shared vehicles. (38.3%)
- Other: (0.8%) ____________________

Q57 ...and what percentage of your travel distance do you expect would be via the shared self-driving vehicles at $0.50 per mile?
______ % (Average = 24.4%)

Q58 Shared self-driving vehicles may offer the option of dynamic ride sharing, in which you may ride all or part of the trip with another passenger, whom you have not met before. The service would be offered at a lower price than a private ride. Would you be interested in this service? (Please select all that apply)

- ❑ Yes, I would be very interested. (10.5%)
- ❑ Yes, I would be somewhat interested. (27.5%)
- ❑ No, I'm not interested in shared vehicles at all. (27.7%)
- ❑ No, I would not feel safe or comfortable riding with someone I don't know. (6.8%)
- ❑ No, I don't want to possibly have to take the time to stop on the way for another passenger. (22.3%)
- ❑ No, I am willing to pay more to ride alone. (20.4%)

Q59 If the dynamic ride sharing option allows you to ride for a price that is 40% lower (for example, $0.60 per mile, compared to $1.00 per mile for riding alone), for what percentage of your rides in the shared self-driving vehicles would you choose the dynamic ride sharing option?
______ % (Average = 18.8%)

Q60 ...and in what situations would you choose the dynamic ride sharing option? (Please select all that apply)

- ❑ When riding alone. (15.6%)
- ❑ When riding with an adult family member or friend. (26.8%)
- ❑ When riding with my child. (7.7%)
- ❑ Only at times of day I feel are safer. (16.3%)
- ❑ For work trips. (9.8%)
- ❑ For shopping trips. (8.7%)
- ❑ For recreational trips. (7.6%)
- ❑ For all trips for which it is feasible. (10.5%)
- ❑ I would not use the service. (51.2%)

Q62 what is the most you would be willing to pay in Dollars to save 30 minutes from a typical 1 hour urban or suburban drive.
______ Dollars (Average = $6.21)

Q63 what is the most you would be willing to pay in Dollars to have your car drive itself for a typical 30 minute urban or suburban drive.
______ Dollars (Average = $5.71)

Q64 For this question, please assume the following: You have a rail transit line 1 mile away from home to take you within 1 mile of your final destination, a seat is always available on the train, and the cost of the rail travel is $2. The travel time on the train is 30 minutes, not including travel to and from the rail stations. A shared autonomous vehicle can be ridden to the station, from your home, and then to your final destination, from the ending rail station, costing $4 total. The total travel time for rail travel accessed by shared autonomous vehicle is 40 minutes. Driving all the way to your destination will take 40 minutes and will come with parking costs of $5. Which method would you normally choose to get to your destination?

- ❍ Driving, costing $5 for parking, plus some car ownership and operating costs. (48.2%)
- ❍ Rail, accessed by shared autonomous vehicle at each end, for total cost of $8. (19.0%)
- ❍ Rail, accessed by by another mode, such as walking or cycling. (30.3%)
- ❍ Other: (2.6%) ____________________

Q65 Self-driving vehicles may make it possible for owners to send their vehicles out empty. This may increase the number of cars on the road, and contribute to congestion. In your opinion, what policies should be put in place regarding empty vehicles?

- I believe empty vehicles should be allowed everywhere, even if they increase congestion. (9.6%)
- I believe empty vehicles should be not allowed, or should be heavily tolled in all situations. (24.8%)
- I believe empty vehicles should be allowed, but only at certain times, such as when congestion is not present. (16.2%)
- I believe empty should vehicles should be allowed, but only in areas not prone to congestion. (8.1%)
- I believe empty vehicles should be allowed, but only on certain types of roadway. (9.8%)
- Don't know, or no opinion. (29.4%)
- Other: (2.2%) ____________________

Q66 What do you believe should be the maximum percent of a self-driving vehicle's miles allowed as empty travel for individually owned vehicles and for shared self-driving vehicle fleets?

______ % of miles allowed empty for individually owned vehicles (Average = 19.6%)

______ % of miles allowed empty for shared fleets (Average = 21.2%)

Q67 What do you believe is the maximum distance in miles a self-driving vehicle should be allowed to travel empty for one trip, for individually owned vehicles and for shared self-driving vehicle fleets?

______ Miles for individually owned vehicles (Average = 13.9 miles)

______ Miles for shared fleets (Average = 16.7 miles)

Q68 SECTION 3: FUTURE PURCHASES AND TRAVEL BEHAVIOR Considering all of the information presented in this survey concerning shared, electric, and fully autonomous vehicles, please answer the following questions about you and your household's expected vehicle purchase and travel behavior intentions. For ALL questions on this page, assume the decisions are being made about 10 years in the future. Also, assume that fully self-driving vehicles are available for a premium of $5,000 above the existing purchase price, or an additional $140 added to the existing monthly lease cost. Also assume fully electric vehicles have the same total lifecycle cost as gasoline vehicles, and can be charged to a full 200 mile range in 2 hours at home or 30 minutes at widely available public charging locations. Also assume shared self-driving vehicles are available for $0.65 per mile for private rides and $0.40 per mile for shared rides where another passenger may be picked up or dropped off during your trip

______ What percent of your travel miles will be private rides (including rides with friends or family) in shared self-driving vehicles? (Average = 24.5%)

______ What percent of your travel miles will be shared rides in shared self-driving vehicles? (Average = 14.8%)

Q69 When do you expect your household to purchase or lease its next vehicle?
- Within the next year. (27.8%)
- In 2 years. (23.8%)
- In 3 years. (12.0%)
- In 4 years. (6.2%)
- In 5 years. (9.7%)
- In 6 years (2.6%)
- In 7 years (1.9%)
- In 8 years. (1.2%)
- In 9 years. (0.6%)
- In 10 years. (2.8%)
- In more than 10 years. (4.3%)
- My household does not ever intend to purchase or lease a vehicle. (7.1%)

Q70 Will the vehicle be purchased or leased, new or used?
- Purchase New (50.7%)
- Purchase Used (34.4%)
- Lease New (6.0%)
- Lease Used (2.2%)
- My household does not ever intend to purchase or lease a vehicle. (6.7%)

Q71 What powertrain do you expect this vehicle to have?
- Gasoline (63.1%)
- Diesel (2.6%)
- Hybrid-Electric (not plug-in) (15.5%)
- Plug-in Hybrid (5.1%)
- Fully Electric (8.2%)
- My household does not ever intend to purchase or lease a vehicle (5.5%)

Q73 Will you choose the fully self-driving option?
- Yes (24.0%)
- No (68.7%)
- My household does not ever intend to purchase or lease a vehicle. (7.3%)

Q74 When do you next expect your household to sell, trade in, or donate a vehicle?
- Within the next year. (20.9%)
- In 2 years. (19.9%)
- In 3 years. (11.1%)
- In 4 years. (5.4%)
- In 5 years. (10.8%)
- In 6 years. (3.0%)
- In 7 years. (1.8%)
- In 8 years. (1.5%)
- In 9 years. (0.4%)
- In 10 years. (2.0%)
- In more than 10 years. (5.0%)
- My household does not ever intend to sell, trade in, or donate a vehicle. (18.3%)

Q77 SECTION 4: FUTURE HOUSEHOLD LOCATION Are you actively considering moving in the near future?
- Yes, I am actively considering moving. (24.4%)
- No, I am not actively considering moving. (75.6%)

Display This Question:
If Are you actively considering moving in the near future? Yes Is Selected

Q78 Do you expect your move to occur within the next year?
- Yes, I expect to move within the next year. (60.6%)
- No, I do not expect to move within the next year. (39.4%)

Display This Question:
If Are you actively considering moving in the near future? Yes Is Selected

Q79 Thinking about your home's proximity to the city center you currently live nearest to, where will your new home be in relation to the city center it is nearest to?
- Closer to city center. (29.3%)
- Farther away from the city center. (38.0%)
- Same distance from the city center. (32.7%)

Display This Question:
If Are you actively considering moving in the near future? Yes Is Selected

Q80 What type of residence do you expect to move into?
- Detached single family home (60.6%)
- Duplex (1.9%)
- Townhome (8.8%)
- Apartment or condo in a residential-only building of 6 floors or less (17.3%)
- Apartment or condo in a mixed-use building (which also has retail, restaurants or offices in the same building) of 6 floors or less (0.7%)
- Apartment or condo in a building of 7 floors or more (5.2%)
- Other: (5.4%) ____________________

Display This Question:
If Are you actively considering moving in the near future? Yes Is Selected

Q81 Would the availability of shared and privately-owned self-driving vehicles have an effect on where you choose to move?

- Yes, I would move closer to the city center. (14.8%)
- Yes, I would move farther away from the city center. (9.7%)
- Possibly, but it would not change my distance to the city center. (16.4%)
- No, it would not affect where I choose to move. (59.1%)

Display This Question:
If Are you actively considering moving in the near future? Yes Is Selected

Q82 Would availability of shared and privately-owned self-driving vehicles change the type of residence you move into?

- Yes, I would instead move into a detached single family home. (15.5%)
- Yes, I would instead move into a duplex. (1.0%)
- Yes, I would instead move into a townhome. (3.2%)
- Yes, I would instead move into an apartment or condo in a residential only building of 6 floors or less. (2.2%)
- Yes, I would instead move into an apartment or condo in a mixed-use building (which also has retail, restaurants or offices in the same building) of 6 floors or less. (1.8%)
- Yes, I would instead move into an apartment or condo in a building of 7 floors or more. (0.2%)
- Yes, but I'm not sure how it would affect my choice. (4.7%)
- No, it would not affect the type of residence I choose to move into. (70.7%)
- Other: (0.6%) ____________________

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