July 2017

Autonomous Vehicles: An Empirical Assessment of Consumers' Perceptions, Intended Adoption, and Impacts on Household Vehicle Ownership

Nikhil Menon
University of South Florida, nikhilmenon@mail.usf.edu

Autonomous Vehicles: An Empirical Assessment of Consumers' Perceptions, Intended Adoption, and Impacts on Household Vehicle Ownership

by

Nikhil Menon

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Civil Engineering
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

Co-Major Professor: Yu Zhang, Ph.D.
Co-Major Professor: Abdul Pinjari, Ph.D.
Fred Mannering, Ph.D.
Grisselle Centeno, Ph.D.
Yingling Fan, Ph.D.

Date of Approval:
May 30, 2017

Keywords: Public Opinion, Surveys, Shared Mobility, Driverless Vehicles, Cluster Analysis

DEDICATION

To consciousness.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my co-advisors Dr. Yu Zhang, and Dr. Abdul Pinjari for their unwavering support through my time here at the University of South Florida (USF). Their vision and direction have been the guiding light in my research culminating in this dissertation. I leave their tutelage rich with academic/professional experience and the readiness to face challenges that lie outside of grad school.

Besides my co-advisors, I would be remiss not to thank Dr. Fred Mannering for everything he has done for me since he joined USF in 2015. Dr. Mannering's words of wisdom and encouragement are one of the pivotal factors behind my successful completion of this dissertation and our conversations remain my single biggest source of inspiration when I am at crossroads. He's taught me a whole lot more than the academic and research rigors. And for that, I am forever indebted to him.

I would like to acknowledge my dissertation committee members, Dr. Grisselle Centeno, and Dr. Yingling Fan for all their inputs and guidance during my Ph.D. They were able to bring in an outsider's perspective into my research and I feel their comments/feedback have been of immense utility when positioning my work on a global stage. In addition to my committee members, I would like to thank my mentors Dr. Pei-Sung Lin, Dr. Seckin Ozkul, and Dr. Robert Bertini for molding me into who I am today – as a researcher and more importantly as a human being.

I would also like to thank my research partners (The American Automobile Association – South) for their invaluable assistance and guidance during the data collection process. My sincere thanks also to everyone at the Center for Urban Transportation Research (CUTR), and the Department of Civil & Environmental Engineering (CEE-USF) who have only been encouraging and supportive of their students' success. I leave USF with fond memories of a great workplace – one where I have managed to build professional as well as personal relationships. Here, I have had the privilege of sharing physical and intellectual space with some wonderful colleagues: Makarand, Qing, Rui, Jacob, Yuan, MD, Maz, Chunfu, Jorge, Saul, Melanie, and others who made my journey very memorable with their support, guidance, and company through this journey.

Last but not least, this work would be incomplete without paying tribute to some amazing humans who have helped me get over the finish line with relative sanity. Achan, Amma, and Vijay: thank you for the unconditional love and encouragement during every stage of my life. I am unsure if I will ever be able to repay you guys for everything you have done for me so far in life. Shivali: thank you for being such an inspiration, our friendship, and the million pick me-ups in the last three years. Apoorva: your words keep me grounded and long may that continue. Stephanie: thank you for being a believer in my abilities and always reinforcing positive thoughts into my head. Minas, Artemis, and Master (João): thanks for all the amazing memories and friendship since 2011 - I look forward to seeing you all again. Friends from Portugal and Professors from IST Lisbon: thank you for being such amazing hosts and providing me with a great learning experience that motivated me to pursue my doctoral studies. The B07 batch and everyone at CEE, NIT Calicut: thank you for taking me onboard as one of you, and being my silent cheerleaders. I would not be here without your blessing.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Emerging automotive and transportation technologies have provided revolutionary possibilities in the way we might travel in the future. Major car manufacturers and technology giants have demonstrated significant progress in advancing and testing autonomous vehicles in real-life traffic conditions. Governmental agencies are grappling with how to plan transportation systems for a world with autonomous vehicles. Past research has shown that not all technologies are immediately welcomed by the public. Autonomous Vehicles would have to likely go through a similar phase, and would need to overcome not just technological challenges but also social barriers for successful penetration into the marketplace. Most previous studies on consumer opinions, and potential adoption of these technologies provide only descriptive, univariate analyses that fail to extract deeper insights on consumers' perceptions, and their intended adoption of autonomous vehicles.

Multi-population surveys were conducted to obtain data on consumers' perceptions, their intended adoption, and eventual use of autonomous vehicles. Descriptive results revealed that around one-fifth of the respondents were unfamiliar about this technology, with larger shares of the younger generations expressing unfamiliarity. Questions on intended adoption of autonomous vehicles were asked across two stages of the survey and results revealed the merit of providing information to the recipients which seem to have assisted them in making more informed decisions about their intended adoption (or non-adoption process). 40% of the respondents were unlikely to adopt autonomous vehicles with a further 20% being unsure, presently. When analyzed across

generations, it was seen that higher shares of older generations were unlikely to adopt autonomous vehicles than their younger counterparts. In addition to adoption, other interesting insights on use of autonomous vehicles, and travel behavioral implications of autonomous vehicles were also obtained in this analysis.

Considering the vast market potential of this technology, it is important to obtain insights on possible differences in adoption (or non-adoption) across various consumer market segments. The current dissertation fills these gaps in the literature by providing an in-depth understanding of the potential market segments of autonomous vehicle consumers, and revealing the factors influencing their adoption (or non-adoption of autonomous vehicles). Two-step cluster analysis of consumers' perceptions of potential benefits and concerns with autonomous vehicles reveal four distinct consumer market segments – the benefits-dominated market segment, the concerns-dominated market segment, the uncertain market segment, and the well-informed market segment. The insights obtained are further used to uncover various triggers influencing the adoption (or non-adoption) of autonomous vehicles across these market segments. It can be seen that in addition to the influence of sociodemographics, various other factors such as current travel characteristics, crash history, and current vehicle purchase inventory have significant influences in the adoption process across each market segment. The results from this exercise provide autonomous vehicle stakeholders with a more in-depth understanding of the potential market segments interested (or uninterested) in adopting autonomous vehicles, which could be used to develop enhanced marketing and policy initiatives to achieve better outcomes.

Considering the high initial cost of autonomous vehicles, novel business models like shared autonomous vehicles (SAVs), could emerge as possible alternatives to individually owning, and operating autonomous vehicles. The recent emergence of popular rideshare giants, such as Uber

and Lyft, into the SAV market have further brought some discussion on possible alterations to household vehicle ownership models in a shared environment. Previous research simulating SAV fleets in a gridded city network reveal the cost benefits of having shared autonomous vehicles in comparison to owning and individually operating them. This study looks into the implications of shared autonomous vehicles on current household vehicle ownership and uncovers the factors influencing the relinquishment of a household vehicle to use shared autonomous vehicles for commute trips. Results show that the effect of relinquishing household vehicles is different among single- and multi-vehicle households with different triggers such as socio-demographics, current travel characteristics, crash severities, and vehicle purchase histories influencing the relinquishment of household vehicles.

CHAPTER 1: INTRODUCTION

1.1 Background

According to a report released by the National Highway Traffic Safety Administration (NHTSA), 90% of all traffic crashes are due to human error (NHTSA, 2008). Research and development over the past few years in the automobile and technology industries have made significant leaps in bringing computerization into our vehicles. Newer car models include features such as adaptive cruise control, parking assist, and lane keeping assist systems that would enhance the safety aspects while riding these vehicles. The objective with such innovation is to slowly computerize the driving process, i.e., to eliminate the need for a human driver to drive these vehicles. Autonomous vehicles (AVs) are a category of vehicles that can drive by themselves with little to no need for a human driver. They sense their surrounding environment with the help of advanced techniques such as RADAR, LIDAR, GPS, and computer vision to navigate from origin to destination. There is a lot of discussion on the influence of autonomous vehicles on the way we might travel, and governmental agencies are grappling with how to plan transportation systems for such technologies.

The race to develop and test autonomous vehicles has heated up with many major automotive manufacturers (such as Tesla, Audi, and General Motors), technology giants (i.e., Google, and Apple), and ridesharing services (such as Uber, and Lyft) fervently involved in rolling out their version of a driverless car to the general public (Smiechowski 2014; Dowling, 2015; Musil, 2015; Tesla, 2015; Brewster, 2016; Kosoff, 2016). As of the year 2016, six U.S. states –

Nevada, Florida, California, Tennessee, Utah, and Michigan – and the District of Columbia have passed laws permitting the testing of autonomous vehicles on highways. Additionally, cities like Pittsburgh and San Francisco have opened its doors for similar kinds of testing of emerging vehicle technologies as well (Brewster, 2016; Lomas, 2017). The introduction of testing procedures has also led to a lot of speculation on forecasts predicting the market penetration of these technologies, which seem to vary widely – ranging from 2025 to as late as 2040 and 2050.

1.2 Motivation

Research has shown that not all emerging technologies are immediately welcomed into the society by the general public. Most technologies require decades of development and innovative market growth to saturate their potential markets. Even then, in addition to some early-adopters, most technologies have a share of consumers who will always be close-minded about them (Moore, 2002; Heffner et al., 2007). It is very likely that the same pattern would follow with autonomous vehicles (AVs) and they would need to overcome not just technological challenges bur also these social barriers for successful penetration into the marketplace.

A majority of the previous studies on public opinions regarding autonomous vehicles (J. D. Power, 2012; Intel, 2013; Cisco, 2013; Casley et al., 2013; Carinsurance.com, 2013; Seapine Software, 2014; Pew Research Center, 2014; Insurance.com, 2014; Howard & Dai, 2014; Schoettle & Sivak, 2014; Kyriakidis et al., 2014, KPMG, 2013; Underwood, 2014) provide only descriptive univariate analyses and fail to provide deeper insights on the influence of many individual-level attributes on consumers' perceptions and intended adoption of these technologies (with few notable exceptions). Even at a descriptive level, there is little evidence of the existence of generational-level differences in intended adoption (or non-adoption) of autonomous vehicles. This is important as a lot of the recent discussions have focused on the fact that fewer Millennials (respondents under the age of 35, presently) are getting their driving licenses (UMTRI, 2011) and their declining patterns of car ownership (Badger, 2014). This is in stark contrast to the older generations who have traditionally equated car ownership with freedom/independence.

As for reasons mentioned above, it is not entirely unfathomable that there may be different triggers towards the adoption (or non-adoption) of emerging technologies among the different generations. Considering the market potential of autonomous vehicles, there are interesting insights to be obtained by understanding possible differences in generational-level preferences towards the adoption (or non-adoption) of autonomous vehicles to plan for an effective future with them. Assuming that everyone across a generation behaves a certain way towards new technologies is itself a broad-based assumption to make. Prior research has addressed these issues with the identification of consumer market segments that contain subgroups with similar behavioral characteristics. Based on the vast market potential of autonomous vehicles, there is a lot of merit in enhancing our understanding of such market segments (if they exist) in order to better analyze their triggers for adoption (or non-adoption) and effectively guide tomorrow's policies.

Considering the high initial cost of owning these technologies, there is a lot of discussion and debate on the possible emergence of innovative transportation modes such as shared autonomous vehicles (SAVs) which could be an inexpensive, on-demand mobility service. Previous research has already simulated shared autonomous fleets in a gridded city network and shown cost incentives in comparison to individually owning and operating vehicles (Fagnant & Kockelman, 2015a). These developments have further been accelerated by the foray of popular ridesharing services such as Uber and Lyft with the aim to develop their versions of autonomous vehicles (Somerville, 2016), thereby underlining the need to analyze possible shifts in household vehicle ownership with the introduction of shared autonomous vehicles. While previous studies have addressed changes in household vehicle ownership due to the emergence of car- and ride-sharing services, there haven't been any advances in understanding these effects with the introduction of shared autonomous vehicles, to the best of the author's knowledge.

1.3 Research Objectives

The study aims to address the gaps in the literature by setting out the following objectives:

- *Assess Public Opinions on Autonomous Vehicles*

The first objective of this study is to assess public opinions on autonomous vehicles. To meet this objective, data collection is initiated through the dissemination of multi-population surveys. These surveys elicit public opinion on autonomous vehicles – their familiarity with autonomous vehicles, their opinions on the proposed benefits and concerns with autonomous vehicles, their likelihood of adoption (or non-adoption) of autonomous vehicles, and their most preferred way to use autonomous vehicles when they become available in the market. The current study differs from previous works by delving in-depth into understanding public opinions on this emerging vehicle technology at a gender- and generational-level, thereby hoping to elicit deeper insights into respondents' preferences and attitudes.

- *Understanding Consumers' Perceptions and Intended Adoption of Autonomous Vehicles*

The second objective of this study is achieved through a two-stage process. In the first stage, autonomous vehicle consumer market segments are identified through consumers' perceptions of the benefits and concerns with autonomous vehicles. This is done by applying two-step cluster analysis to come up with market segments (or clusters) that consist of subgroups of respondents with similar characteristics. Once this is done, econometric models are estimated to determine the probability of a respondent belonging to a particular market segment. While this kind of analysis provides insights on the makeup of the consumer market segments, it does not, as of yet, provide any insights on their intended adoption. The second stage of the analysis – understanding intended adoption of autonomous vehicles – involves the estimation of separate econometric models to understand the factors influencing intended adoption (or non-adoption) of autonomous vehicles for each market segment. It is likely that there are different triggers for intended adoption (or non-adoption). Therefore, this effort provides a better understanding of intended adoption across the previously determined consumer market segments.

- *The Potential Impacts of Shared Autonomous Vehicles on Household Vehicle Ownership*

The final objective of this study is to investigate the potential impacts of shared autonomous vehicles on household vehicle ownership. Econometric models shall be estimated to assess people's likelihood to relinquish a household vehicle (reducing their household vehicle ownership level by one) in the presence of shared autonomous vehicles. While household vehicle ownership decisions are a medium-term consequence, this effort shall provide an initial assessment for comparison of changes in people's intentions to be part of a sharing environment.

1.4 Organization of the Dissertation

The rest of this dissertation is organized as follows: Chapter 2 will provide a comprehensive review of the past research efforts (especially, related surveys – public opinion, focus group/expert opinion) that have been conducted in order to understand consumers' perceptions of autonomous vehicles and their initial insights into the adoption of the same. Chapter 3 will present the data collection efforts as well as the preliminary results from the multi-population surveys (i.e., the first objective) conducted as part of this study – namely on public opinion on the addition of enhanced safety/automation features in vehicles, public opinions on the benefits and concerns with autonomous vehicles, their intended adoption of autonomous vehicles and anticipated travel behavioral impacts with autonomous vehicles. Chapter 4 presents a comprehensive understanding of consumers' perceptions and intended adoption of autonomous vehicles (i.e., the second objective). Chapter 5 will provide the implications of shared autonomous vehicles on household vehicle ownership. Chapter 6 of this dissertation will present the conclusions from this study and a discussion on future research in light of the findings from the current study.

CHAPTER 2: LITERATURE REVIEW

2.1 Assessing Consumer Opinions about Autonomous Vehicles

Table 2-1 summarizes the key findings from related studies – public opinion and expert/focus group, about consumers' perceptions and their intended adoption of autonomous vehicles. Within a few decades, autonomous vehicles (AVs) have the potential to significantly change the way people travel. While different organizations have produced varied levels of forecasts for the market penetration of autonomous vehicles, experts believe that autonomous vehicles would be commonplace and available for mass consumption by 2040 (Begg, 2014; UC Davis, 2017). Even though individual-level benefits with autonomous vehicles could be realized as early as 2025, the majority of the system-level enhancements are only expected around 2050 (Litman, 2017). Current literature shows that the general public aspires to live in a driverless world (Intel, 2013) and have both great expectations and concerns over autonomous vehicles (Schoettle & Sivak, 2014; Schoettle & Sivak, 2015; CTA, 2016; Deloitte, 2017; DTO, 2017). The expected benefits include increased safety (Intel, 2013; NHTSA, 2014; Begg, 2014; Gfk, 2015; Bansal et al., 2016; BikePGH, 2017), improved fuel efficiency, and reductions in traffic and emissions (Intel, 2013).

On the other hand, the most cited concerns are equipment failure, liability (Underwood, 2014; Bansal et al., 2016) software security, and privacy issues regarding data sharing (Seapine Software, 2014; Schoettle & Sivak, 2014; Schoettle & Sivak, 2015; AAA, 2016; Bloomberg, 2016). Other potential apprehensions to the consumer include the ability of the autonomous vehicle to interact with human-driven vehicles, interacting with animals on the road (Autotrader, 2017), and navigating successfully through heavily congested areas (Bloomberg, 2016; State Farm, 2016). In some cases, respondents are unsure as to whether the benefits of autonomous vehicles would outweigh the costs and the risks associated with the technology (DTO, 2017). And in some others, respondents simply do not wish to adopt emerging vehicle technologies such as autonomous vehicles because they seemingly trust their driving skill over the technology (AAA, 2016; Kelly Blue Book, 2016).

Besides the expectations and concerns, the literature also reveals that the intended adoption of autonomous vehicles is sensitive to economic incentives (Howard & Dai, 2014; Kyriakidis et al., 2014; JD Power, 2014). For instance, respondents' interests in purchasing AVs increased remarkably with the promise of cheaper car insurance (Carinsurance.com, 2013; Insurance.com, 2014; CTA, 2016) and declined sharply after the cost for the technology was revealed (J.D. Power, 2012). As for their willingness to pay studies have shown that households are ready to pay anywhere between $4,900 and $10,000 (and sometimes beyond) for complete automation (Bansal et al., 2016, Deloitte, 2017; Daziano et al., 2017).

Findings from the literature reveal that the intended adoption of autonomous vehicles is also sensitive to the level of trust placed by consumers on the manufacturer of the autonomous vehicle technology. While a majority of respondents prefer that the Silicon Valley takes charge of developing the software for autonomous vehicles (World Economic Forum, 2015; AlixPartners, 2016; UC Davis, 2017), a similar majority also believe that the traditional automakers are best placed to build these autonomous vehicles over technology companies (World Economic Forum, 2015; AlixPartners, 2016; Volvo, 2016; Deloitte, 2017) – with some even welcoming startups specialized in autonomous vehicle technologies to take the lead (Deloitte, 2017).

A number of studies provide understanding on how demographic and other socio-economic factors influence the adoption of AV technology. Generally, males are more interested in purchasing autonomous vehicles while females have more concerns about riding in, and purchasing AVs (J.D. Power, 2012; Schoettle & Sivak, 2014; AAA, 2016; Bansal et al., 2016; Bloomberg, 2016). Other factors such as younger ages, and higher education levels are found to be positively correlated with higher interests in autonomous vehicles (J.D. Power, 2012; Pew Research Center, 2014; Nerd Wallet, 2015; Bansal et al., 2016; Abraham et al., 2016; Bloomberg, 2016; JD Power, 2017). At a finer level, there has been some initial work on eliciting public opinions regarding consumers' intended adoption of autonomous vehicles for different population segments. Research reveals that current household location might have an influence on the intended adoption of autonomous vehicles – with urban and suburban residents showing a more positive attitude towards riding in an autonomous vehicle relative to their rural counterparts (Pew Research Center, 2014; Bansal et al., 2016).

Few studies have attempted to dissect autonomous vehicle consumers across the various generations – i.e., the millennials (age < 35, presently), the Gen-X-ers (ages 35-49, presently), the baby boomers (ages 50-64, presently), and the great generation (65+ years, presently) – to elicit more insightful findings. For instance, Abraham et al., (2016) reveal that younger adults are seemingly more comfortable with the idea of full automation while the older adults seem to prefer partial automation capabilities to help the driver. This is in slight contrast to a few other studies that conclude that the younger generation is more comfortable with the idea of autonomous driving, also preferring the installation of enhanced safety and automation features relative to their older counterparts (AAA, 2016; Autotrader, 2017; JD Power, 2017).

It is also interesting how consumers' perceptions of emerging vehicle technologies such as autonomous vehicles are impacted by their opinion on the robustness of the technology. As fully autonomous vehicles (NHTSA Level 4) are unlikely to be available for the foreseeable future, many automobile giants have already initiated the introduction of partially automated features that assist the driver and enhance the driving experience. These features, such as adaptive cruise control, blind spot detection systems, collision avoidance systems, and lane departure warning systems are already available in many car models from the year 2015. It can be seen that a large majority of the respondents welcome these semi-autonomous features in their vehicles (AAA, 2016; Kelly Blue Book, 2016; Abraham et al., 2016; CTA, 2016). At the outset, consumers are more likely to be comfortable with the idea of riding self-driving cars in areas with few or no vehicles (Bloomberg, 2016) and for rides with shorter durations of time (Bloomberg, 2016). At a system level, experts argue the need for cars to be able to effectively communicate with each other for the successful implementation of fully autonomous systems (Underwood, 2014). Lastly, consumers also feel public demonstrations of autonomous vehicles could enhance trust, erode preexisting notions, and foster a more positive opinion (Bloomberg, 2016).

While most surveys are general in their understanding of public opinions about autonomous vehicles and its proposed implications on travel behavior, Bonnefon et al., (2016) conducted a series of six web surveys to enhance our understanding of some social dilemmas with autonomous vehicles. This study provided insights into the aspects of morality when it comes to an autonomous vehicle. Scenarios were prepared, and respondents were asked to make choices. While respondents felt that it would be moral for the autonomous vehicle to sacrifice one passenger than killing ten pedestrians on the road, they reported a significantly lower likelihood of buying an autonomous vehicle programmed for self-sacrificing at such situations.

Table 2-1 Key Findings on Consumer Opinions about Autonomous Vehicles from Related Surveys

Survey	Approach	Sample	Key Findings
J.D. Power (2012)	Field Survey	17,400 U.S. vehicle owners	1. 37% of the respondents expressed interest in purchasing AVs 2. 20% of the respondents stayed interested once a $3000 cost was revealed 3. Respondents with the highest interest in AVs at market price are males (25%), those between the ages of 18 and 37 (30%), and those living in urban areas (30%).
Intel (2013)	Web Survey	12,000 adults in 8 countries	1. 44% Americans would like to live in driverless cities. 2. Perceived benefits include reductions in the number of traffic incidents (40%), traffic (38%) and the amount of carbon emissions (34%) 3. More than half of U.S. respondents would anonymously share travel information for improved commuting and parking
Cisco (2013)	-	1500 consumers in 10 countries	1. 57% of all respondents trust AVs 2. 60% of U.S. respondents trust driverless cars and 48% would let their kids ride in one
Carinsurance.com (2013)	Web Survey	2,000 U.S. licensed drivers	1. 20% of the respondents will purchase AVs when they become available. 90% of the respondents will consider AVs if cheaper insurance were offered 2. The lack of trust in technology is a major hurdle for the adoption of AVs
Casley et al. (2013)	Web Survey	467 respondents	1. 82% of respondents felt safety was the important factor affecting their adoption. 2. Legislation (12%) and Costs (6%) were other important factors.
Seapine Software (2014)	Web Survey	2,039 adults in the U.S.	1. 88% of the respondents would be worried about riding in an AV. 2. Respondents were concerned about equipment failure (79%), liability (59%), software security (52%) and privacy issues regarding data sharing (37%).
Pew Research Center (2014)	Phone Interviews	1,001 adults in the U.S.	1. 48% respondents would like to ride in AVs. 2. Respondents with higher education were more likely to ride in AVs. 3. Urban and Suburban residents were more likely to ride in AVs than their rural counterparts.
Insurance.com (2014)	Web Survey	2,000 U.S. licensed drivers	1. 22% of the respondents will purchase AVs. 38% will purchase AVs if cheaper insurance was offered. 2. 61% believe that the computer is incapable of making decisions in a better way than the humans.
Kyriakidis et al. (2014)	Web Survey	5,000 international respondents	1. Respondents indicated that manual driving was more enjoyable over fully automated driving. 2. 22% of the respondents were not willing to pay extra money for AVs whereas 5% indicated they were willing to pay more than USD 30,000 for the same. 3. 69% of the respondents expected fully automated vehicles to achieve a market share of 50% by 2050.

Table 2-1 (Continued)

Howard & Dai (2014)	Field Survey	107 respondents in California	1. Over 2/3 of the respondents were concerned about the cost of AV. 2. Safety plays an important role for AV adoption.
JD Power (2014)	Field Survey	15,171 U.S. vehicle owners	1. 24% owners expressed interest in paying to have autonomous driving mode ($3000) in their next vehicle – up from 20% in 2012.
Schoettle & Sivak (2014)	Web Survey	1,533 adults in 3 countries	1. The majority of the respondents had previously heard of AVs (66%), had a positive initial opinion and high expectations about the benefits of AV technology. 2. The majority of respondents expressed high levels of concern about riding in AVs including security issues and lacked of trust in AV technology. 3. 55% of the respondents were unwilling to pay extra for the technology despite a desire to utilize the technology. 4. Females expressed higher level of concerns with AVs and were more cautious about the benefits
Gfk (2015)	Web Survey	5,800 consumers across 6 countries	1. 66% respondents found self-driving cars appealing. 2. Safety was cited as a key benefit with self-driving car by 54% of the respondents.
World Economic Forum (2015)	Web Survey	5,500 consumers in 10 countries	1. 60% respondents are ready to embrace driverless vehicles but only 16% trust a tech company to produce a vehicle. 2. 69% respondents were more trusting of a self-driving vehicle built in a partnership between auto and tech majors.
Schoettle & Sivak (2015)	Web Survey	618 respondents	1. 46% respondents prefer to retain full control while driving, while 39% prefer a partially self-driving vehicle with occasional control by the driver. 2. Two-thirds of the respondents moderately or very concerned about riding in a completely-self driven vehicle. About half have the same levels of concern in a partially self-driving vehicle. 3. 59% prefer a combination of both sound, vibration, and visual warnings to notify drivers when it is necessary to take control of the vehicle.
Nerd Wallet (2015)	Web Survey	1028 American adults	1. 53% respondents between 18 and 29 years are "very interested" or "somewhat interested" in owning a self-driving car vs 41% respondents aged 30 or above. 2. 51% respondents willing to wait at least 3 years after self-driving cars are available to purchase them.
Bansal et al. (2016)	Web Survey	347 Austinites	1. Primary benefit with autonomous vehicles: Fewer crashes. 2. Primary concern with autonomous vehicles: Legal liability and regulation. 3. Respondents more likely to pay for level 4 automation than level 3 automation ($7,253 vs $3,000). 4. Higher income, tech-savvy males, who lived in urban areas, with more crash experience possessed a greater interest and WTP for autonomous vehicle technologies.

Table 2-1 (Continued)

Volvo (2016)	Web Survey	50,000 respondents	1. 72% respondents believe that driving manually is a luxury that must be preserved. 2. 55% say they want steering wheel in a fully autonomous car. 3. 69% feel that making decisions about their journey (route they take) is important. 4. 78% would use their time productively when riding in an autonomous car. 5. 72% feel that car manufacturers, not tech companies, will make autonomous driving a reality 6. 86% feel that government and local authorities are slow to plan for autonomous cars 7. 79% feel that car manufacturers, not owners, must take responsibility if an accident occurs when is driving autonomously
Bonnefon et al. (2016)	Web Surveys	1928 respondents across 6 surveys	1. 76% of respondents felt that it would be moral for AVs to sacrifice one passenger than kill ten pedestrians (n=182) 2. 23% of respondents felt that AVs should not sacrifice its passenger if only one pedestrian could be saved (n=451) 3. Respondents reported a significantly lower likelihood for buying an AV which was programmed for sacrificing themselves (and/or their family member inside an EV) for greater good. 4. Even though respondents felt that self-sacrificing AVs were good and welcome them on the road, a large majority of them were sceptical of purchasing these AVs.
AlixPartners (2016)	Web Survey	1,517 respondents	1. 73% respondents said they would want autonomous vehicles to take over all their driving needs. 2. 90% would let an autonomous vehicle handle their commute if they could occasionally take the wheel. 3. 41% respondents preferred Silicon Valley to take over the development of software for autonomous vehicles; 26% preferred Japanese automakers while 17% and 7% chose U.S. and European carmakers respectively. 4. When it came to building these cars, majority (27%) preferred U.S. auto makers; 25% preferred the Japanese.
Kelly Blue Book (2016)	Web Survey	2,264 respondents from 12 to 64 years	1. Private vehicle ownership would be phased out by 2025. 2. 6 in 10 customers would be interested in buying autonomous cars with partial capabilities by 2020. 3. More than half (51%) the respondents preferred to have full control over their vehicles than a safer roadway.
State Farm (2016)	Web Survey	1,000 consumers	1. Majority of respondents (48%) would eat than read texts (45%) or send texts (43%) with the spare time in a self-driving car. 2. Higher share of consumers are aware of self-driving technology and confident about navigating safely.

Table 2-1 (Continued)

AAA (2016)	Telephone Survey	1,832 adults	1. Only 20% U.S. drivers trust an autonomous vehicle to drive itself with them in it. 2. Women (81%) are more likely than men (67%) to be afraid to allow an autonomous vehicle to drive itself with them in it. 3. Baby boomers (82%) more afraid than younger generation (69%) to allow an autonomous vehicle to drive itself with them in it. 4. Men are more likely than women to trust semi-autonomous technology 5. 61% of drivers want at least semi-autonomous technology in their next vehicle purchase. 6. Millennials most likely to want self-parking technology in their next vehicle (33%) compared to Gen-Xers (20%) or Baby Boomers (22%). 7. Most drivers who don't want autonomous tech in their next vehicle cite trusting their driving skills more than the technology (84%).
Abraham et al. (2016)	Web Survey	2,954 respondents	1. 28% of the respondents were very happy with the technology in their current vehicle. Further 42% of the respondents liked most of the features. 2. Younger adults are more comfortable with the idea of full automation whereas older adults are more comfortable using partial autonomous features in order to help the driver.
CTA (2016)	Web Survey	2,001 respondents	1. 70% respondents were ready to try out an autonomous car 2. 46% drivers did not want any self-driving features 3. 39% drivers wanted no more than partial automation capabilities 4. 82% were pleased with the potential from reduction in driving under the influence of alcohol or drugs and aggressive driving. 5. Almost 80% felt autonomous vehicles would lower insurance rates.
Bloomberg (2016)	Web Survey	1,005 adult consumers	1. 39% respondents would consider riding in a self-driving car in areas with few/no other vehicles 2. 33% respondents would consider riding in a self-driving car for short rides under 10 minutes while only 16% would consider riding through heavily congested areas. 3. Higher shares of degree holders would consider riding in a self-driving car through heavily congested than non-degree respondents. More men and more respondents under 40 would also do the same over women/respondents over the age of 40 years. 4. 60% of the respondents would be very concerned about computer system malfunctions involving a crash and 33% were of the opinion that these were likely to happen in an autonomous vehicle. 5. 52% respondents felt that seeing an autonomous vehicle operate first hand would increase their adoption

Table 2-1 (Continued)

Deloitte (2017)	Web Survey	22,000 consumers in 17 countries	1. 74% Americans believe fully autonomous vehicles will not be safe. More than two-thirds (68%) of Americans said they will change their opinion with a proven track record of autonomous vehicles. 2. 47% trust a traditional car manufacturer to bring autonomous vehicles to market. 3. 27% would trust a new company specializing in autonomous vehicle technology. 4. Americans' willingness to pay for autonomous vehicles was $925.
Daziano et al (2017)	Web Survey	1260 individuals from a nation-wide online panel	1. Average household is willing to pay $3,500 for partial automation and $4,900 for full automation. 2. Significant fraction of respondents are willing to pay more than $10,000 for full automation
DTO (2017)	Field Survey	158,000 visitors	1. 30% would be extremely concerned about riding in a self-driving car. 2. Majority respondents unsure whether the benefits of self-driving cars would outweigh the costs and risks of the technology.
Autotrader (2017)	Web Survey	1,020 vehicle owners	1. Parents are thrice as likely to own a vehicle with autonomous features, than non-parents. 2. 58% millennials have a positive opinion of self-driving cars. 36% of the overall population have a positive opinion about self-driving cars. 3. 49% respondents indicated that they would give up control of the vehicle in exchange for some free time. 4. A large share of consumers are not concerned about the ability of an autonomous vehicle to react in unexpected traffic situations – encountering a deer (42%), interaction with non-autonomous vehicles (57%), interacting with pedestrians/bicyclists (56%).
BikePGH (2017)	Web Survey	798 Pittsburgh residents	1. 49% approve the use of Pittsburgh streets as a proving ground for AVs. 2. Residents felt 6 times safer sharing the road with AVs vs human-driven vehicles. 3. 62% members believe that AVs have the potential to reduce fatalities. 1. 27% felt regulatory authorities should prevent AVs from operating in school zones.
JD Power (2017)	Web Survey	8,500 consumers	1. 40% of the baby-boomers do not see any benefits to self-driving vehicles. 2. 34% of Gen-X-ers and 44% of baby boomers do not trust autonomous vehicles. 3. Younger generations are far more comfortable than their older counterparts in trusting technology that takes control of their vehicles.
KPMG (2013)	Focus Group	32 licensed drivers	1. Women are more likely to be willing to use AVs than men.
Begg (2014)	Focus Group	3,500 London transport professionals	1. 20% professionals believe that NHTSA level 4 AVs would be commonplace on UK roads by 2040 2. 60% professionals agree that AVs would improve the safety for all road users

Table 2-1 (Continued)

BikePGH (2017)	Focus Group	321 donor members	1. 53% approve the use of Pittsburgh streets as a proving ground for AVs. 2. Members felt 5 times safer sharing the road with AVs vs human-driven vehicles. 3. 72% members believe that AVs have the potential to reduce fatalities. 4. 19% felt regulatory authorities should prevent AVs from operating in school zones.
Underwood (2014)	Expert Opinion	217 AV experts at the AV Symposium'14.	1. Legal liability and regulation are the most difficult barriers towards implementation of fully automated vehicles. 2. 27% felt that automated systems should be twice as safe as what they were today before they could be used in public. 3. 60% of the respondents felt that automated driving systems would be sold as original equipment on new vehicles, as against retrofits to existing vehicles. 4. Two-thirds of the experts also felt the need for vehicles to communicate with each other for the successful implementation of fully automated systems.
UC Davis (2017)	Expert Opinion	40 experts from government and non-profit organizations	1. 70% feel that by 2040 fully autonomous vehicles will make up for 20% of vehicles sold in the U.S. 2. 67% feel Google is in the best position to integrate these new vehicle technologies; 64% Tesla; 48% Uber. 3. 77% believe that the benefits of shared, autonomous vehicles won't be shared across all income levels. 4. 80% feel that the sale of autonomous vehicles will result in more greenhouse gas emission vehicles being emitted without policy actions taking place.

2.2 Impacts of Autonomous Vehicles on Future Travel

Autonomous vehicles are set to impact the way we travel in the future. These impacts could be short-term, medium-term, and long-term in nature. Short term impacts of autonomous vehicles could center on the scope of activities one could engage inside the autonomous vehicle (Anderson et al., 2014). Additionally, extensive improvements in transportation network capacity (Pinjari et al., 2013; Anderson et al., 2014) and, safety (Merian, 2013) are set to herald in the short term. Medium-term impacts involve alterations in the existing car ownership models with the introduction of innovative modes such as shared autonomous vehicles (Anderson et al., 2014; Fagnant & Kockelman, 2015a). Changes in car ownership models can have an impact on mode choice highlighting the possible increase in the significance of certain transportation modes over the others (Anderson et al., 2014; Freemark, 2015; Levin and Boyles, 2015). The longer term impacts of autonomous vehicles mainly involve household location choices and their overarching influence on land-use patterns. As the stress from driving decreases, road users can travel longer distances while also being productive during this travel. This could lead to more flexibility in residential, work and/or school locations, which can bring about a variety of economic/social benefits and impact urban development patterns (Pendyala & Bhat, 2014; Anderson et al., 2014; Labi & Saeed, 2015).

The promise of car-sharing as a model for vehicle ownership was established even before the focus shifted towards autonomous vehicles. Shaheen et al. (2009) concluded that one of the most promising aspects of car-sharing was reduced vehicle ownership. They found car-sharing had the potential to decrease between 4.6 and 20 cars (per shared-use vehicle) from a typical transportation network. There are signs that the introduction of autonomous vehicles (and the subsequent availability of innovative modes such as shared autonomous vehicles) could lead to declining car ownership levels as well. Some other travel behavior related effects arising from car-sharing seem to be the perceived reduction in emissions (Firnkorn & Muller, 2012). As much as there are positives with the introduction of autonomous vehicles, as is the case with all emerging technologies, there are likely to be some negative externalities as well.

Smith (2012) suggests that a gradual shift towards autonomous vehicles would also be accompanied by higher vehicle miles traveled (VMT), higher sprawl, and increased vehicular emissions. With the potential to drive by themselves with no need for a human driver, congestion might still remain the same (or even increase) as a lot of autonomous vehicles might be involved in zero person trips (Barnard, 2016). While traditional car-sharing studies have shown that there is a possibility to decrease VMT, Fagnant & Kockelman (2014) showed through their model that shared autonomous vehicles (SAVs) could potentially lead to higher levels of VMT and emissions than the levels observed before. The argument on increased emissions is backed up by a recent study where 40 transportation experts were surveyed by UC Davis (2017). They believe that the introduction of autonomous vehicles would lead to more greenhouse gas emission vehicles being emitted without policy actions taking place. Predicting travel behavioral impacts, especially those that focus on understanding car ownership patterns in a world with AVs is a challenging task (Litman, 2017). There are several studies that have been conducted on this topic, but the majority of them have simulated scenarios to predict the outcomes.

Burns et al. (2013) studied the impact of carpooling and car-sharing on autonomous vehicles using queuing and network modeling approaches to develop an analytical model to relate the area of the region, the mean trip length, the mean trip rate and its variation, mean vehicle speeds, fleet size, driverless vehicle fleet performance and cost. Results indicated that autonomous vehicles could provide better mobility experiences at much lower costs in a variety of land use settings – resulting in greater efficiencies, cost savings leading to sustainability benefits to the consumers.

Spieser et al. (2014) conducted a study with the objective of understanding the potential benefits of a fleet of autonomous vehicles in Singapore. The authors hypothesized that this fleet would replace all modes of personal transport in Singapore. Another assumption was that the shared autonomous vehicle (SAV) fleet would provide a similar level of convenience as private cars, yet be as sustainable as public transit – if they were able to return to their charging station or be able to pick up the next passenger by driving to their origins by themselves. It was found that peak waiting times could be reduced to less than 15 minutes if there were 300,000 SAVs on the road. These 300,000 SAVs were slated to replace the nearly 800,000 personal vehicles operating in Singapore in the year 2011. Cost benefits were also accrued at such a stage, where this level of service was to be provided at 50 percent of the total mobility costs compared to individually owning and operating a vehicle.

Lastly, Fagnant & Kockelman (2014) set out to model the implications of a scenario with 3.5% shared autonomous vehicle (SAV) mode share instead of a 100% mode share hypothesized by Spieser et.al (2014). The results from this study showed that each SAV could serve about 31-41 travelers per day, with an average wait time of fewer than 20 seconds in a hypothetically gridded city modeled after Austin, TX. A more than 5-minute wait for a SAV was faced only by 0.5 percent of the travelers, and it was found that each SAV had the ability to replace nearly 12 privately owned vehicles.

KPMG (2012) concluded that autonomous vehicles could contribute significantly towards a redefinition of car ownership and expand opportunities for the use of shared vehicles. The report talks of a world where these vehicles could be summoned when needed and returned when the trip is completed. This would mean that travelers would no longer need to own their vehicles and could instead depend on on-demand mobility options available to them. This would eventually lead to fewer car sales – which is a challenge at that hands of traditional auto manufacturers and suppliers. This opinion is largely shared by consumers as well. In a recent survey by Kelly Blue Book (2016), a majority of the respondents felt that private vehicle ownership would be phased out by 2025. These observations also gain impetus in today's discussions with popular ridesharing service Lyft predicting that car ownership will *all but end* by 2025 (Kosoff, 2016).

2.3 Presence of Knowledge Gaps in the Current Literature

There are some knowledge gaps in the literature for understanding how consumers' perceptions along with their demographic factors influence their intended adoption of autonomous vehicles. Therefore, it becomes cumbersome to address any factors that might impact the widespread adoption of these technologies. Not just that, but some additional, important factors that could potentially influence perceptions, and intended adoption (or non-adoption) are not discussed in the past literature. Some examples include familiarity with autonomous vehicles, the influence of current travel characteristics, and crash history. Most previous studies (with a few notable exceptions such as Bansal et al., 2016 and Daziano et al., 2017) only involve descriptive, univariate analyses of demographic differences in perceptions, and the influence of demographic/attitudinal factors influencing the intended adoption of autonomous vehicles. While these analyses are insightful, they do not attempt to disentangle the influence of one factor from another.

This dissertation fills these gaps by conducting multivariate analyses of different factors that may influence the adoption of autonomous vehicles by focusing on consumers' perceptions of these technologies. This kind of additional insight will lead to the identification of the main reasons behind the observed differences in adopting autonomous vehicles. It is important to look deeper into demographic-level differences in preferences for emerging vehicle technologies. This would foster a better understanding of the consumer market segments that are more likely to adopt such technologies at an early stage, and target specialized educational, and marketing campaigns aimed at them for achieving better outcomes.

Additionally, past literature on the anticipated impacts of autonomous vehicles on future travel has largely focused on short-term impacts of autonomous vehicles. There are several studies (speculative as well as simulation-based) that focus on autonomous vehicles' implications on network capacity (Shladover, 2012; Pinjari et al., 2013; Anderson et al., 2014; Childress et al., 2015) as well as potential safety enhancements (Mearian, 2013; Fagnant & Kockelman, 2013; Anderson et al., 2014; Labi et al., 2015). With fully autonomous vehicles being a few years away from becoming a reality and the current uncertainty regarding the intricacies of this technology, understanding the long-term implications is beyond the scope of this study.

However, current research contributes to state of the art by attempting to understand medium-term implications (namely, household vehicle ownership impacts) with the introduction of shared autonomous vehicles. Previous work done on understanding changes in household vehicle ownership with the introduction of autonomous vehicles are either speculative or simulation-based in nature. While simulation studies are useful in understanding these impacts, they assume that the general public is on board with these new technologies. The multi-population surveys conducted as part of this study enables to better understand public opinions on a variety of topics of interest including household vehicle relinquishment, preferences for shared autonomous vehicles as well as implications for future travel in a world with autonomous vehicles.

CHAPTER 3: DATA AND PRELIMINARY RESULTS

Web-based multi-population surveys were administered to obtain data to achieve the objectives set out in this dissertation. This section introduces the survey questionnaire design as well as a summary of the preliminary descriptive insights obtained through these surveys.

3.1 Questionnaire Design, Data Collection, and Quality Control

The Research Integrity and Compliance Office at The University of South Florida (USF) processed this study request and determined it as "Exempt" from the Institutional Review Board review (IRB#: Pro00016056). Two surveys targeting – (i) the students, faculty, and staff of the University of South Florida system (USF) (all three campuses – Tampa, St. Petersburg, and Sarasota-Manatee), and (ii) members of American Automobile Association (AAA) – South were designed using the survey platforms SurveyMonkey (SurveyMonkey, 2015), and Qualtrics respectively. These surveys were sent for data collection during the months of April, and June 2015 respectively. The survey for the university population consisted of 94 questions while that of the AAA membership consisted of 75 questions divided into the following three sections:

I. *General Information*: This section elicited respondent demographics (such as age, gender, educational level, household size, annual household income), information on their current travel characteristics (such as the most commonly used mode for various trips, average one-way distance, total time spent on travel per day), their crash history (such as vehicular damage level, injury severity level), and information on their vehicle purchase inventory (e.g., number of vehicles in the household, total purchase price), including available safety/automation features in their current vehicles.

II. *Consumer Perception of Autonomous Vehicles (AVs)*: This section elicited information on respondents' familiarity with AVs, their likelihood of using AVs (before being queried on the benefits and concerns), their perception of the benefits with AVs, their perceptions on the concerns, and other aspects with autonomous vehicles (AVs), their likelihood of using AVs when they become available. This section also included questions on their preferred way of using AVs (such as own, rent, use as transportation service), their willingness to pay for AVs, and lastly, their willingness to include safety and automation features.

III. *Anticipated Impacts of Autonomous Vehicles (AVs)*: This section included questions aimed at understanding the potential impacts of AVs on individuals' travel behavior (such as the most preferred activity inside the AV, future vehicle sizes, impact on housing locations), and future transportation systems (such as willingness to use different types of shared AVs, and potential concerns with the use of shared AVs).

A representative sample of the students, faculty, and staff of the USF system was selected through various university channels to receive emails with information regarding the survey objectives and a web link to the survey. Data as collected from USF for three weeks during the month of April 2015. Once this data was collected, a customized version of the multi-population survey was designed keeping in mind the members of the AAA South Division. Officials from the AAA helped dissipate this survey to a representative sample of their membership database. This data collection effort lasted three weeks during the month of June 2015. No incentives were provided for the participants in this survey, and respondents were free to leave the survey at any point in time.

Table 3-1 Quality Control Procedures and Sanity Checks Employed with Data from Multi-Population Surveys

Parameter	**USF Survey**	**AAA Survey**	**Research Database (USF+AAA)**
Total Recorded Responses (Initial Sample Size)	**1156**	**2338**	**3494**
Quality Control Measures (indicates number of responses removed during various checks applied)			
Respondent age < 18 years	4	-	4
Respondents refused consent to take the survey	-	26	26
Incomplete responses (failed to complete even one part of the survey)	225	198	423
Premature completion (respondents who spent less than 7 mins in answering the surveys; average time for completion = 15 mins)	2	48	50
Erroneous responses (respondents answering most questions with the same categorical response – all As, all Bs, etc.)	2	41	43
Missing entries in any of the variables of interest	122	168	291
Total Useful Responses (Final Sample Size)	**801**	**1857**	**2658**

A total of 3494 responses were recorded from both the surveys (1156 from USF, and 2338 from AAA, respectively). However, not all of these responses were of good quality. Therefore, the responses were subjected to quality control and sanity checks. It was found that incomplete responses were a major reason for the reduction in sample size with nearly 13% of the respondents failing to fully respond to even one section of the survey. The research team conducted several beta-tests to ensure that the survey questions were administered in simple English with the aim of providing a clear understanding of the expectations to the respondents. Considering the non-incentivized nature of the survey, as well as the survey length, the attrition levels are within acceptable limits. The application of the quality control procedures shown in Table 3-1 reduced the initial sample size to a final usable sample size of 2658 from the two surveys. Further details on these steps are as shown in the table above.

Table 3-2 Respondent and Household Demographics Variables Available to Model Consumers' Perceptions, and Intended Adoption of Autonomous Vehicles

	Survey (n=2658)		Females (n=1248)		Males (n=1410)		Millennials (n=619)		Generation X (n=409)		Baby Boomers (n=843)		Great Generation (n=787)	
Variable Description	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Respondent and Household Demographics														
Gender of the respondent (1 if male, 0 otherwise)	0.530	0.499	--	--	--	--	0.362	0.481	0.469	0.500	0.534	0.499	0.691	0.462
Age of the respondent (1 if under 35 years, 0 otherwise)	0.181	0.385	0.250	0.433	0.121	0.326	--	--	--	--	--	--	--	--
Age of the respondent (1 if 50 years or older, 0 otherwise)	0.613	0.487	0.510	0.500	0.705	0.456	--	--	--	--	--	--	--	--
Age of the respondent (1 if 65 years or older, 0 otherwise)	0.296	0.457	0.195	0.396	0.386	0.487	--	--	--	--	--	--	--	--
Ethnicity of respondent (1 if White, 0 otherwise)	0.839	0.367	0.816	0.388	0.860	0.347	0.680	0.467	0.814	0.389	0.867	0.340	0.947	0.225
Ethnicity of respondent (1 if Hispanic/Black, 0 otherwise	0.096	0.294	0.114	0.318	0.079	0.271	0.170	0.376	0.130	0.336	0.087	0.281	0.029	0.169
Postgraduate (1 if Graduate degree holder, 0 otherwise)	0.351	0.477	0.347	0.476	0.355	0.479	0.275	0.447	0.401	0.491	0.359	0.480	0.376	0.484
Annual Household Income (1 if Less than $50,000, 0 otherwise)	0.264	0.441	0.342	0.475	0.195	0.396	0.595	0.491	0.188	0.391	0.135	0.342	0.183	0.387
Annual Household Income (1 if Less than $100,000, 0 otherwise)	0.458	0.498	0.532	0.499	0.393	0.489	0.754	0.431	0.357	0.480	0.327	0.470	0.418	0.494
Household size (1 if there is 1 person, 0 otherwise)	0.186	0.389	0.231	0.422	0.147	0.354	0.150	0.358	0.164	0.371	0.181	0.386	0.231	0.422
Household size (1 if more than 2 persons, 0 otherwise)	0.326	0.469	0.342	0.474	0.311	0.463	0.480	0.500	0.597	0.491	0.301	0.459	0.889	0.285
Licensed drivers (1 if zero drivers, 0 otherwise)	0.015	0.122	0.018	0.135	0.012	0.109	0.013	0.113	0.015	0.120	0.008	0.091	0.024	0.154
Licensed drivers (1 if more than 2 drivers, 0 otherwise)	0.216	0.412	0.228	0.420	0.205	0.404	0.352	0.478	0.225	0.418	0.246	0.431	0.072	0.259
Household vehicle ownership (minimum: 0, maximum: 5)	2.889	1.122	2.743	1.161	3.02	1.072	2.319	1.053	2.863	1.107	3.282	1.169	2.928	0.931
Household vehicle ownership (1 if zero cars, 0 otherwise)	0.084	0.277	0.114	0.318	0.057	0.231	0.227	0.419	0.108	0.310	0.036	0.186	0.010	0.101
Household vehicle ownership (1 if 2 or more cars, 0 otherwise)	0.617	0.486	0.531	0.499	0.693	0.461	0.369	0.483	0.636	0.482	0.757	0.429	0.653	0.476

3.2 Respondent and Household Demographics

Table 3-2 shows the sociodemographic characteristics of the survey respondents. The complete survey dataset (n=2658) polled 53% males and 47% females. Roughly one-third (36%) of the Millennials, and half of the Gen-X-ers (47%), as well as the baby boomers (53%) polled, were males. On the other hand, there were twice as many males who belonged to the great generation (respondents who were 65 years or above) than their female counterparts. A majority of the respondents are of White ethnicity, thereby limiting ethnicity comparisons to white vs non-white in most cases. There is a higher representation of Hispanic/Black among the younger generations (17% among millennials and 13% among Gen-X-ers) than their older counterparts. Nearly one-third of the respondents (35%) possessed a graduate degree across all population segments (except millennials, mostly owing to their age splits).

While one-fourth of the respondents (26%) belonged to low-income households (with annual income less than USD 50,000), more than half of the respondents (54%) belong to high-income households as well (with annual income more than USD 100,000). The survey polled a higher percentage of women belonging to high-income households (47%) relative to low-income households (36%). It is also unsurprising that among the generations, millennials polled the highest share of respondents belonging to low-income households (60%) while they also polled the least share of respondents belonging to the high-income households (25%). Around one-fifth of the survey respondents (19%) lived in single-person households while a further one-third (33%) lived in multi-person households (households with more than 2 persons). It was interesting to note that a higher share of older respondents who live in single- and multi-person person households than their younger counterparts except the baby boomers in multi-person households.

When it came to licensed drivers in the household, it was interesting to note that the trends obtained from the survey respondents were in line with those established in the previous literature. While a higher share of males possessed driving licenses, it was also seen that almost every baby boomer surveyed for this study belonged to households with at least 1 licensed driver. Car ownership was another aspect that was investigated across the survey respondents. Results reveal a higher number of cars owned by male respondent households (3.02) than female respondent households (2.74). Interestingly, millennial respondents belong to the most number of zero-car households (23%) and the least number of multi-car households (37%) – results that are in line with recent literature on millennials' aversion towards owning vehicles as well as their attitudes towards possibly using public transportation for their trips.

3.3 Current Travel Characteristics and Crash History

As can be seen from Table 3-3, larger shares of the older generations (i.e., the baby boomers and the great generation) do not commute to work relative to their younger counterparts. Two-thirds of the survey respondents (68%) drive alone to their commute with larger shares of female drive alone commuters than males. One-fourth of the survey respondents (25%) spend, on average, a minimum of 30 mins one-way for their commute, and one-third of the respondents (32%) spend on average, a minimum of 60 minutes for all travel in a day. It was also observed that almost three-fourths of the survey respondents (71%) had been involved in a crash. One-fifth of the survey respondents (21%) suffered complete vehicle damage while more than half of them (59%) suffered no injuries during their crash.

3.4 Consumers' Opinions on the Use of Safety/Automation Features in their Vehicles

Recent findings from the literature show that fully autonomous vehicles are at least a few decades away. Therefore, it is foreseeable that consumers will be exposed to semi-autonomous technology before fully autonomous vehicles penetrate into the marketplace. To account for this scenario, the multi-population surveys sought respondent opinions on the presence of enhanced safety and automation features in their current vehicles. Once these opinions were sought, respondents were also enquired about their interest in adopting enhanced safety/automation features for their next vehicular purchase. While some of the safety/automation features are currently only available in high-end models, the main purpose of this exercise was to understand public opinions and preferences about adding enhanced safety/automation features to enhance their driving experience.

Results from Table 3-4 indicate that more than half (51%) of the respondents had no safety/automation features in their current vehicle. A further one-third (36%) had backup cameras, with 15% of the respondents also indicating the presence of blind spot monitoring systems. Adaptive Headlamps and Adaptive Cruise Control were available in close to one-tenth of the respondents' current vehicles. Predictably, a very low share of respondents had advanced features such as Left Turn Assist, Do Not Pass Warning Systems, Intersection Movement Assist, and Driver Drowsiness Detection Systems – as these are only currently available in very high-end car models.

When asked about their preferences for advanced safety/automation features in their next vehicular purchase, significant shares of respondents were interested in adding safety features such as Night Vision Assist, Collision Avoidance Systems, and Blind Spot Monitoring Systems to their vehicles. Respondents did not seem very enthused about adding wireless internet or self-parking systems to their vehicles. It would be interesting to see if there are gender- or generational-level differences in preferences for wireless internet as well as self-parking systems in future vehicles. Lastly, it was observed that only 5% of the respondents were not interested in adding any safety/automation features to their next vehicle.

Table 3-3 Current Travel Characteristics, and Crash History Variables Available to Model Consumers' Perceptions, and Intended Adoption of Autonomous Vehicles

Variable Description	**Survey (n=2658)**		**Females (n=1248)**		**Males (n=1410)**		**Millennials (n=619)**		**Generation X (n=409)**		**Baby Boomers (n=843)**		**Great Generation (n=787)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Current Travel Characteristics and Crash History														
Commute mode (1 if Do Not Commute, 0 otherwise)	0.219	0.414	0.182	0.386	0.252	0.434	0.032	0.177	0.049	0.216	0.163	0.369	0.514	0.500
Commute mode (1 if Drive Alone, 0 otherwise)	0.678	0.467	0.720	0.449	0.640	0.480	0.793	0.405	0.839	0.368	0.769	0.422	0.405	0.491
One way commute time (1 if 30 minutes or more, 0 otherwise)	0.246	0.431	0.263	0.440	0.231	0.421	0.374	0.484	0.308	0.462	0.243	0.429	0.116	0.320
Total daily travel time (1 if 60 minutes or more, 0 otherwise)	0.323	0.468	0.348	0.477	0.302	0.459	0.464	0.499	0.403	0.491	0.315	0.465	0.180	0.385
Crash history (1 if involved in a crash, 0 otherwise)	0.715	0.451	0.685	0.465	0.742	0.437	0.647	0.478	0.726	0.446	0.760	0.427	0.715	0.452
Vehicle damage level (1 if complete vehicle damage, 0 otherwise)	0.214	0.410	0.206	0.405	0.221	0.415	0.199	0.400	0.247	0.432	0.237	0.426	0.183	0.387
Crash injury severity (1 if no injury, 0 otherwise)	0.588	0.492	0.578	0.494	0.598	0.491	0.578	0.494	0.550	0.498	0.559	0.497	0.648	0.478

Table 3-4 Consumers' Opinions on the Use of Safety/Automation Features in their Vehicles across Population Segments

Variable Description	**Survey (n=2658)**	**Females (n=1248)**	**Males (n=1410)**	**Millennials (n=619)**	**Generation X (n=409)**	**Baby Boomers (n=843)**	**Great Generation (n=787)**
New Safety/Automation Features in Vehicles							
Night Vision Assist							
Currently available	5.72	6.73	4.75	4.20	2.44	6.76	7.12
Interested in future vehicle	58.16	55.77	60.21	34.09	56.72	65.95	69.12
Collision Avoidance System							
Currently available	8.13	8.01	8.16	3.88	6.36	9.25	10.80
Interested in future vehicle	55.42	50.00	60.14	36.83	52.81	60.14	65.95
Lane Keeping Assist							

Table 3-4 (Continued)

Currently available	6.09	4.57	7.38	3.39	3.42	6.88	8.39
Interested in future vehicle	47.37	44.31	50.00	35.06	44.99	49.35	55.78
Blind spot Monitoring System							
Currently available	14.97	12.50	17.09	7.59	8.31	16.25	22.49
Interested in future vehicle	64.48	60.74	67.73	37.80	63.08	72.48	77.26
Driver Drowsiness Detection Systems							
Currently available	1.84	1.12	2.41	0.97	0.49	2.25	2.41
Interested in future vehicle	42.17	37.82	45.96	27.30	39.36	47.21	49.56
Wireless Internet							
Currently available	7.37	5.53	8.94	2.75	3.42	8.07	11.94
Interested in future vehicle	31.79	32.45	31.13	29.73	35.45	33.93	28.84
Backup Cameras							
Currently available	36.87	31.41	41.63	20.68	32.27	41.16	47.01
Interested in future vehicle	62.00	56.49	66.81	37.16	59.66	68.09	75.86
Self-Parking Systems							
Currently available	1.69	1.12	2.13	0.48	1.71	1.54	2.41
Interested in future vehicle	32.77	35.74	30.07	34.25	36.43	35.11	26.81
Adaptive Headlamps							
Currently available	13.13	12.42	13.69	11.15	9.54	13.64	15.63
Interested in future vehicle	55.12	52.16	57.66	33.76	54.28	61.21	65.44
Adaptive Cruise Control (ACC)							
Currently available	11.29	11.70	10.85	9.05	6.36	9.73	16.90
Interested in future vehicle	48.27	42.47	53.33	35.86	45.72	49.70	57.43
Do Not Pass Warning (DNPW) Systems							
Currently available	1.81	1.60	1.91	0.16	0.49	2.61	2.54
Interested in future vehicle	44.06	43.51	44.47	32.31	41.32	47.21	50.95
Left Turn Assist (LTA)							
Currently available	1.39	1.20	1.49	0.81	0.24	1.42	2.03
Interested in future vehicle	42.93	42.95	42.84	32.31	37.90	45.31	50.95
Intersection Movement Assist (IMA)							
Currently available	0.64	0.24	0.92	0.16	0.24	0.59	0.89
Interested in future vehicle	43.00	42.71	43.19	33.60	39.36	44.48	50.32
None							

Table 3-4 (Continued)

Currently available	50.60	53.13	48.30	61.07	56.23	48.64	41.17
Interested in future vehicle	5.72	4.41	6.81	0.97	5.38	7.59	7.24

Table 3-5 Consumers' Opinions on Familiarity and the Potential Benefits with Autonomous Vehicles across Population Segments

Variable Description	**Survey (n=2658)**	**Females (n=1248)**	**Males (n=1410)**	**Millennials (n=619)**	**Generation X (n=409)**	**Baby Boomers (n=843)**	**Great Generation (n=787)**
Familiarity with AVs							
Familiarity with AVs before taking this survey							
Not at all familiar	20.50	26.12	15.53	26.05	22.98	18.01	17.53
Slightly/ Moderately Familiar	73.48	69.47	77.02	67.80	69.44	74.41	79.03
Extremely Familiar	6.02	4.41	7.45	6.15	7.58	7.58	3.43
Opinions on the Benefits with AVs							
Fewer traffic crashes/increased roadway safety							
Unlikely	17.98	17.23	18.65	18.61	18.34	17.89	17.83
Unsure	22.46	24.28	20.85	14.08	20.05	24.64	27.98
Likely	59.56	58.49	60.50	67.31	61.61	57.46	54.19
Less traffic congestion							
Unlikely	39.92	41.27	38.72	39.64	36.67	39.93	41.80
Unsure	25.51	25.72	25.32	14.89	23.23	28.08	32.27
Likely	34.57	33.01	35.96	45.47	40.10	31.99	25.92
Less stressful driving experience							
Unlikely	23.89	23.88	23.90	21.68	24.94	23.82	25.16
Unsure	18.89	19.47	18.37	11.17	14.67	20.73	25.16
Likely	57.22	56.65	57.73	67.15	60.39	55.45	49.68
More productive (than driving) use of travel time							
Unlikely	20.35	19.15	21.42	17.96	19.07	20.85	22.36
Unsure	22.08	22.92	21.35	10.68	14.43	25.24	31.64
Likely	57.56	57.93	57.23	71.36	66.50	53.91	46.00
Lower car insurance rates							
Unlikely	35.14	33.33	36.74	35.92	32.52	34.13	36.98
Unsure	27.65	28.21	27.16	20.55	24.69	29.15	33.16

Table 3-5 (Continued)

Likely	37.21	38.46	36.10	43.53	42.79	36.73	29.86
Increased fuel efficiency							
Unlikely	18.81	17.23	20.21	17.48	15.65	18.96	21.35
Unsure	26.90	28.21	25.74	19.58	25.92	30.81	28.97
Likely	54.29	54.57	54.04	62.94	58.44	50.24	49.68
Lower vehicle emissions							
Unlikely	23.18	21.79	24.40	25.08	20.78	22.27	23.89
Unsure	36.27	37.66	35.04	26.05	33.74	40.28	41.30
Likely	40.56	40.54	40.57	48.87	45.48	37.44	34.82

Table 3-6 Consumers' Opinions on Potential Concerns with Autonomous Vehicles across Population Segments

Variable Description	**Survey (n=2658)**	**Females (n=1248)**	**Males (n=1410)**	**Millennials (n=619)**	**Generation X (n=409)**	**Baby Boomers (n=843)**	**Great Generation (n=787)**
Opinions on the Concerns with AVs							
Safety of the AV occupants, other road users							
Not at all concerned	4.93	4.73	5.11	7.77	3.91	4.74	3.43
Slightly/Moderately concerned	51.77	49.60	53.69	53.40	52.08	51.54	50.57
Extremely concerned	28.44	31.81	25.46	33.66	32.03	27.96	23.00
Unsure	14.86	13.86	15.74	5.18	11.98	15.76	23.00
System/equipment failure							
Not at all concerned	2.56	2.08	2.98	3.24	3.18	1.90	2.41
Slightly/Moderately concerned	45.75	43.27	47.94	45.31	46.21	45.02	46.63
Extremely concerned	36.64	41.43	32.41	46.44	40.59	36.61	26.94
Unsure	15.05	13.22	16.67	5.02	10.02	16.47	24.02
Performance in unexpected traffic/poor weather							
Not at all concerned	3.05	3.29	2.84	3.88	2.44	3.44	2.29
Slightly/Moderately concerned	45.71	43.83	47.38	41.75	46.70	45.85	48.16
Extremely concerned	35.74	39.26	32.62	48.87	39.36	33.65	25.79
Unsure	15.50	13.62	17.16	5.50	11.49	17.06	23.76
Giving up control of the steering wheel to the vehicle							

Table 3-6 (Continued)

Not at all concerned	10.50	10.42	10.57	15.37	9.54	9.36	8.39
Slightly/Moderately concerned	43.45	41.75	44.96	38.35	43.28	45.02	45.87
Extremely concerned	31.23	34.62	28.23	39.64	34.47	28.91	25.41
Unsure	14.82	13.22	16.24	6.63	12.71	16.71	20.33
Loss in human driving skill over time							
Not at all concerned	11.17	11.94	10.50	20.55	11.74	8.41	6.48
Slightly/Moderately concerned	47.67	47.60	47.73	47.25	47.43	47.16	48.67
Extremely concerned	27.95	29.09	26.95	26.54	26.89	31.28	26.05
Unsure	13.21	11.38	14.82	5.66	13.94	13.15	18.81
Privacy risks from data tracking							
Not at all concerned	10.01	10.02	10.00	14.72	12.47	7.82	7.37
Slightly/Moderately concerned	43.79	43.99	43.62	47.90	44.25	40.05	44.35
Extremely concerned	30.62	32.13	29.29	30.58	31.05	35.66	25.03
Unsure	15.58	13.86	17.09	6.80	12.22	16.47	23.25
Difficulty in determining liability during crashes							
Not at all concerned	8.62	9.21	8.09	13.59	10.51	7.94	4.45
Slightly/Moderately concerned	43.72	43.11	44.26	50.81	46.21	39.10	41.80
Extremely concerned	26.22	28.53	24.18	27.67	24.69	27.61	24.40
Unsure	21.44	19.15	23.48	7.93	18.58	25.36	29.35

Gender-level segregation of respondents' opinions revealed more-or-less similar trends observed by male and female respondents, with a larger share of males expressing interest in adding enhanced safety/automation features to their future vehicles. At a generational-level, some interesting insights are observed – 1) fewer shares of millennials have any safety/automation features installed in their current vehicles, relative to their older counterparts, 2) fewer shares of millennials also seem to express interest for installing enhanced safety/automation features in their next vehicle, which is rather surprising. While the preference for technologies remains same across the generations, it is interesting to observe the vastly fewer shares of millennials who seem to want these features in their next vehicle. There seems to be an increasing preference for safety/automation features among the older generations, compared to their younger cohorts. While it could be an indication of their better purchasing power relative to the younger generations, it could also be interesting considering recent discussions on how the older generations are not seemingly pro-technology.

3.5 Consumers' Opinions on their Familiarity with Autonomous Vehicles

It was hypothesized that familiarity with autonomous vehicles through discussions and discourse in various media would enhance respondents' understanding of the benefits and concerns with them. This would make them better equipped to provide their input for the purpose of this research. Keeping this in mind, survey respondents were asked to indicate their level of familiarity with autonomous vehicles before the research team provided any details about this technology. Results from Table 3-5 indicate that one-fifth of the respondents are unfamiliar about autonomous vehicles at the time of this survey. Higher shares of males seem familiar about autonomous vehicles relative to females – which is unsurprising considering their possibly higher levels of exposure towards discussions and discourse on such technologies. Across the four generations, it is rather surprising to see the higher shares of unfamiliarity about autonomous vehicles among millennials in comparison to their older counterparts. Also, interestingly, a significant share of the great generation seem familiar about autonomous vehicles. Perhaps this is only a reflection of this sample, but this may be something worth investigating in future studies using this sample.

3.6 Consumers' Perceptions of the Potential Benefits with Autonomous Vehicles

Survey respondents indicated three main benefits – (1) fewer traffic crashes and more roadway safety, (2) more productive (than driving) use of travel time, and (3) less stressful driving experience. While millennials and Gen-X-ers foresee an increase in productivity while riding in an autonomous vehicle (more productive use of travel time), the most likely benefit of the older generations (i.e., the baby boomers and the great generation) seems to be focused on increased safety (fewer traffic crashes and increased roadway safety). Additionally, survey respondents across genders or generations indicated that less traffic congestion was least likely with the introduction of autonomous vehicles. This makes intuitive sense considering recent discussions on the possibility of additional vehicle miles traveled with autonomous vehicles executing empty person trips (Smith, 2012).

While more than half of the respondents (at gender- and generational-level) foresee increased fuel efficiency benefits with autonomous vehicles (possibly due to their smoother acceleration and deceleration curves, and advantages from platooning), more than one-third of respondents (36%) were unsure about reduced vehicle emissions. These results could have possibly been influenced by their opinion on congestion impacts with autonomous vehicles. To summarize, there seems to be a pattern among older respondents regarding their perceptions of the benefits with autonomous vehicles. Older respondents seem less and less optimistic about the benefits of autonomous vehicles, in comparison to their younger counterparts. This is consistent with popular intuition. It is very likely that the older respondents are more in favor of ubiquitous modes of transportation and are likely to be more skeptical of emerging technology that is set to take control of their vehicle from their hands. Additionally, this might also be a psychological response to the possible perception of the loss of freedom with the emergence of new technology that assists/takes over their driving.

3.7 Consumers' Perceptions on the Potential Concerns with Autonomous Vehicles

Table 3-6 lists consumers' perceptions of the concerns with autonomous vehicles. Respondents indicated their top three concerns as (1) system/equipment failure, (2) performance in unexpected traffic/poor weather conditions and (3) safety of the AV occupant and other road users. These results are in accordance with previous studies which indicate similar findings (Underwood, 2014; Bansal et al., 2016). While female respondents echo general sentiments with respect to their concerns on autonomous vehicles, it is interesting to note that males have slightly different perceptions regarding potential concerns. They seem less *extremely concerned* about said concerns, relative to their female counterparts. Interestingly, higher shares of males also seem to be *unsure* about all potential concerns with autonomous vehicles. In summary, women seem more certain about their perceptions while higher shares of males seem to be on the fence about it.

Looking across generations, results show that as respondent's age, they are less concerned about potential issues arising with autonomous vehicles. Results also reveal an increasing trend in respondent uncertainties over potential concerns with increasing age. The great generation experience higher levels of uncertainty about potential concerns with autonomous vehicles, relative to baby boomers and the younger generations. Among potential issues with autonomous vehicles, respondents at gender- and generational-level seem to be unsure about liability issues in the event of a crash with autonomous vehicles, contributing to the current discussion.

While the biggest concerns for millennials, Gen-X-ers, and baby boomers revolve around safety-related aspects such as the prospect of system failure, the great generation seem most concerned about the loss of driving skill. This is very relevant as these individuals are at the end of their life cycles and they gradually start showing a decline on their physical wellbeing. It is also around this time in their lives that they lose driving privileges; therefore they feel that a technology that replaces them at the driver's seat is set to reduce their skill for driving.

3.8 Consumers' Opinions on their Intended Adoption of Autonomous Vehicles

The multi-population surveys contained questions on consumers' intended adoption of autonomous vehicles. Questions on intended adoption were asked at two stages along the survey – (1) before the survey respondents were provided information on the benefits and concerns with autonomous vehicles, and (2) after the survey respondents were provided information on the benefits and concerns with autonomous vehicles. This was done in order to understand the effectiveness of providing information to the respondents to elicit a well-rounded opinion on their likelihood to adopt (or non-adopt) autonomous vehicle technologies. This study hypothesized that the additional information would eliminate any form of uncertainty in the minds of the respondent.

Before respondents were informed about the potential benefits and concerns with autonomous vehicles, close to one-third of them (37%) were likely to adopt autonomous vehicles when they became available in the market whereas a further 25% of the respondents were unsure about their adoption (or non-adoption) decisions. Once the information was provided to the respondents regarding potential benefits and concerns with autonomous vehicles, it was found that the share of respondents who were unsure about their decisions decreased from 25% to 19%. This 6% decrease was complimented by an increase among the two extreme categories.

Table 3-7 Consumers' Opinions on their Intended Adoption of Autonomous Vehicles across Population Segments

Variable Description	**Survey (n=2658)**	**Females (n=1248)**	**Males (n=1410)**	**Millennials (n=619)**	**Generation X (n=409)**	**Baby Boomers (n=843)**	**Great Generation (n=787)**
Intended adoption of AVs (before asking the questions on benefits and concerns)							
Likelihood of using AVs when they become available							
Unlikely	38.30	37.90	38.65	31.88	34.47	39.45	44.09
Unsure	25.09	26.84	23.55	23.95	24.94	23.70	27.57
Likely	36.61	35.26	37.80	44.17	40.59	36.85	28.34
Intended adoption of AVs (after asking the questions on benefits and concerns)							
Likelihood of using AVs when they become available							
Unlikely	39.24	39.42	39.08	33.33	35.94	39.21	45.62
Unsure	19.86	21.55	18.37	21.04	18.58	19.91	19.57
Likely	40.90	39.02	42.55	45.63	45.48	40.88	34.82
Intended adoption of AVs for different trip purposes							
Likelihood of using AVs for commute trips							
Unlikely	44.81	44.87	44.75	37.70	42.05	44.55	52.10
Unsure	16.40	17.39	15.53	14.08	11.74	15.76	21.35
Likely	38.79	37.74	39.72	48.22	46.21	39.69	26.56
Likelihood of using AVs for grocery trips							
Unlikely	47.14	47.20	47.09	42.56	44.01	45.97	53.62
Unsure	12.19	13.14	11.35	13.11	12.71	13.03	10.29
Likely	40.67	39.66	41.56	44.34	43.28	41.00	36.09
Likelihood of using AVs for long distance business trips							
Unlikely	44.58	44.95	44.26	37.54	40.10	45.02	51.97
Unsure	16.89	18.75	15.25	15.70	16.38	16.59	18.42
Likely	38.53	36.30	40.50	46.76	43.52	38.39	29.61
Likelihood of using AVs for long distance leisure trips							
Unlikely	43.87	44.39	43.40	38.67	40.34	44.08	49.56
Unsure	11.25	12.82	9.86	13.59	12.47	11.49	8.51
Likely	44.88	42.79	46.74	47.73	47.19	44.43	41.93

Table 3-7 (Continued)

Using autonomous vehicles when they are available in the market							
Most preferred way to use AVs							
Own – personal use + family use	36.76	35.26	38.01	38.45	36.67	36.54	35.32
Own – personal + family + earn extra unused	3.69	4.01	3.33	6.14	4.89	3.08	1.40
Own – personal + family + earn extra while use	1.58	1.60	1.49	2.26	1.96	1.19	0.89
Rent	6.88	5.93	7.66	6.30	5.87	6.76	7.62
Transportation service – taxi, public transit	7.04	8.09	6.03	8.40	9.78	7.59	3.56
Neither invest in AV nor use as service	43.79	44.55	43.05	37.32	39.36	44.13	50.44
Using shared autonomous vehicles (SAVs) when they are available in the market (N=1543)							
Most preferred mode of SAVs for commute trips	(N=1543)	(N=608)	(N=935)	(N=53)	(N=230)	(N=640)	(N=620)
Do not undertake commute trips	36.29	34.87	37.11	13.21	17.39	28.28	53.06
Rent AVs of individual owners	1.56	1.15	1.71	1.89	1.30	1.87	0.81
Rent AVs from rental companies	5.25	4.44	5.67	11.32	7.39	6.25	2.42
Share ride with co-passengers in your own AV	5.96	6.91	5.24	9.43	10.00	6.88	2.74
Share ride with AV owner as co-passenger	4.54	5.10	4.06	1.89	5.22	5.94	2.58
Use driverless taxis	4.15	3.95	4.17	11.32	6.52	4.84	1.45
Not interested in using any mode of SAVs	41.74	42.27	41.28	35.85	49.13	44.84	35.81

Therefore, as hypothesized earlier, providing additional information on the benefits and concerns with autonomous vehicles seem to have "warmed up" the respondents to process more information and make them more certain about their adoption (or non-adoption) decisions. The attitudinal/perceptional questions are not only useful in their own right but also assist respondents to better respond to subsequent questions as they are more likely to consider the above-mentioned benefits and concerns in a real setting.

On a gender-level comparison, there is evidence that males are more certain about their adoption (or non-adoption) decisions than their female counterparts. On the other hand, at a generational-level, it can be seen that baby boomers and the great generation express higher resistance towards adopting autonomous vehicles in comparison to their younger counterparts. This is also supplemented by their lower adoption shares in comparison to their younger cohorts. The merits of providing information about the benefits and concerns is seen while comparing across the two genders and the four generations as well. Providing information is seen to be least effective among the millennials (2% reduction in unsure respondents) and the most effective among the great generation (8% reduction in unsure respondents). Moreover, these results on intended adoption (or non-adoption) are in line with the consumers' opinions on the benefits and concerns with autonomous vehicles (refer Tables 3-5 and 3-6). Earlier findings suggested a growing skepticism regarding potential benefits and a growing concern regarding potential issues among the older generations. It is very likely that their perceptions may have influenced their decisions regarding adoption (or non-adoption) of autonomous vehicles.

When asked on their intended adoption of autonomous vehicles for undertaking various trip purposes, respondents seem most unsure about using autonomous vehicles for their commute as well as long distance business trips. Higher shares of males are likely to adopt autonomous vehicles for the different trip purposes than their female counterparts. While the difference between males likely to adopt autonomous vehicles and females likely to adopt autonomous vehicles are marginal for commute and grocery trips, there are significant increases in these categories for both long distance business as well as long distance pleasure trips. Predictably, with respondents' increasing age, they seem less and less likely to adopt autonomous vehicles for their trip purposes.

3.9 Consumers' Opinions on Using Autonomous Vehicles

During the survey, respondent opinions were elicited on their most preferred way to use autonomous vehicles when they become available in the market. While a good majority (44%) of the respondents aren't interested in investing in autonomous vehicles or using it as a service, a further 37% would prefer to own an autonomous vehicle and prefer to use it for personal and family usage. It is interesting to see that only a small share of respondents would like to earn income on the side with their purchased autonomous vehicle. On the other hand, close to 14% of the respondents would prefer to not own autonomous vehicles, but them as a service.

There aren't many deviations from the general pattern observed for using autonomous vehicles when comparisons are made at a gender- and generational-level. Predictably, higher shares of female respondents are not interested in investing in autonomous vehicles or using them as a service. But what's more interesting is the pattern emerging across generations – the older generations seem less enthused about investing in autonomous vehicles, or using them as a service. These results are in line with earlier results obtained on intended adoption of autonomous vehicles (refer section 3.8 and Table 3-7 for details).

Similarly, respondent opinions were also sought on their preferred way of using shared autonomous vehicles for their commute trips (if applicable) when faced with the possibility of the same. Since this was asked as a last section of the survey, there was a considerable amount of respondent attrition experienced which led to a final usable sample of only 1,543 respondents. Based on these numbers, it was found that a majority (42%) were not in favor of using any mode of shared autonomous vehicles for their commute trips, as well as not undertaking any commute trips currently (36%). On a closer look, across a generational-level, it was revealed that the majority of respondents who aborted the survey were the millennials (N=53, refer Table 3-7) – which might explain the high shares of respondents who currently do not undertake any commute trips. Therefore, none of these insights were used for the purpose of this dissertation.

3.10 Consumers' Opinions on the Impacts of Autonomous Vehicles on Travel Behavior

The implications of autonomous vehicles are manifold. Understanding public opinion on future travel with autonomous vehicles will provide autonomous stakeholders some clarity so as to guide policy and discussion. With this in mind, the research team queried respondents for their opinions on the future implications with autonomous vehicles. While this is a vast topic of research which requires in-depth focus to garner insightful findings, the objective of the survey was to provide some initial findings that will assist policymakers to gauge public sentiments. Therefore, the multi-population survey focused on some main aspects such as future vehicular sizes, future residential locations, possible alterations to daily travel time for all activities, and the likelihood of household car ownership in favor of using shared autonomous vehicles for commute trips in households. Consumers' opinions on these scenarios are as shown in Table 3-8.

Table 3-8 Consumers' Opinions on Impacts of Autonomous Vehicles on Travel Behavior across Population Segments

Variable Description	**Survey (n=2658)**	**Females (n=1248)**	**Males (n=1410)**	**Millennials (n=619)**	**Generation X (n=409)**	**Baby Boomers (n=843)**	**Great Generation (n=787)**
Impacts of AVs on Travel Behavior							
Total daily travel time for all trips currently							
Less than 30 minutes	25.06	24.52	25.53	18.45	22.49	25.59	31.00
30-59 minutes	42.59	40.71	44.26	35.11	37.16	42.89	50.95
60-119 minutes	27.13	28.77	25.67	39.32	32.03	25.83	16.39
120 minutes or more	5.23	6.01	4.54	7.12	8.31	5.69	1.65
Total daily travel time for all trips with AVs							
Less than 30 minutes	20.43	20.11	20.71	11.33	16.63	25.83	23.76
30-59 minutes	34.99	32.85	36.88	25.89	31.05	36.14	42.95
60-119 minutes	24.30	23.40	25.11	24.60	30.56	24.53	20.58
120 minutes or more	14.18	15.54	12.98	21.84	13.45	11.14	11.82
Not interested in taking trips with AVs	6.09	8.09	4.33	16.34	8.31	2.37	0.89
Most preferred activity while riding in an AV							
Be alert and watch the road	31.41	32.37	30.50	21.65	26.89	31.67	40.79
Relax and enjoy the outside view	21.67	19.47	23.55	15.51	13.94	21.00	30.88
Work or participate in teleconference	6.17	6.65	5.67	10.66	8.31	5.81	1.52
Browse internet or other social networks	6.06	5.77	6.24	7.59	6.36	7.24	3.05
Watch movies or other entertainment	4.33	4.25	4.33	5.98	5.62	4.63	1.65
Make phone calls/text messages	7.30	7.53	7.02	7.75	10.27	8.42	3.81
Eat/drink	1.62	1.44	1.70	1.62	0.73	1.78	1.52
Sleep/nap	6.73	6.41	6.95	9.53	8.07	5.93	4.32
Read	11.74	13.14	10.43	17.77	14.67	8.66	8.39
Other	2.56	2.08	2.91	0.16	2.69	3.68	2.80
Future vehicle size with AVs							
Larger vehicle size than that currently owned	14.90	15.54	14.33	24.11	16.38	12.20	9.78
Similar vehicle size to that currently owned	78.22	77.40	78.94	67.80	78.24	80.57	83.86
Smaller vehicle size than that currently owned	6.88	7.05	6.74	8.09	5.38	7.23	6.35
Moving farther for more affordable and better housing, with AVs							
Unlikely	56.73	54.17	46.92	39.48	53.55	61.37	66.96
Unsure	24.60	24.20	11.59	23.62	26.89	23.93	24.90
Likely	18.66	21.63	41.49	36.89	19.56	14.69	8.13

Table 3-8 (Continued)

Frequency of using self-parking feature with AVs							
Never	8.92	7.37	10.21	5.01	11.49	10.44	8.51
Almost never	8.43	7.37	9.29	4.36	6.36	8.42	12.33
Occasionally/Sometimes	23.66	22.12	24.96	8.40	19.07	26.33	34.82
Almost every time	23.33	23.08	23.48	22.62	25.43	24.44	21.22
Every time	18.77	20.19	17.45	29.24	20.54	17.44	10.67
Unsure	16.52	19.23	14.04	29.24	15.65	11.98	11.44

Results from the multi-population surveys show that respondents are willing to spend more time traveling in an autonomous vehicle than they currently do in human-driven vehicles. This is illustrated by a decrease in shares of respondents traveling smaller time ranges (<30 mins, 30-59 mins, 60-119 mins) and an increase in shares of respondents who are willing to travel 120 minutes or more in a future with AVs in comparison to their current travel characteristics (14% v/s 5%). While this may also an indication of additional vehicle miles traveled (VMT) in a world with autonomous vehicles, it is also indicative of the possibility of increased congestion with the introduction of autonomous vehicles. Congestion impacts have been discussed in the literature before as well.

Gender-based segregation of data reveals that a higher share of women are likely to travel 120 minutes or more in a world with autonomous vehicles, relative to men. While the reasons for this phenomenon are currently unknown (and maybe only reflective of the current dataset), future research could look into understanding the gender-level differences in total daily additional travel with autonomous vehicles. A higher share of women also think that they will not be interested in taking any trips with autonomous vehicles, in comparison with men (8% v/s 4%).

When the data is segregated across the four generations, there are different travel patterns observed between millennials and the Gen-X-ers in comparison to their older counterparts (i.e., the baby boomers, and the great generation). A higher share of the millennials and the Gen-X-ers currently travel for higher durations than their older cohorts. This is in line with common intuition as the younger generations currently constitute the majority of the work force and are bound to engage in more travel than their older cohorts. When asked about their future total daily travel time with the introduction of autonomous vehicles, a significantly higher share of millennials reported that they would travel for higher durations, relative to their older cohorts. An interesting and somewhat thought-provoking finding from the descriptive analysis was that a significantly high share of millennials are not interested in taking trips with autonomous vehicles in comparison to their older cohorts. This is surprising mainly because of the results obtained on the intended adoption of autonomous vehicles. It seems that while older generations are less likely to adopt autonomous vehicles when they become available, they are willing to use them for undertaking their trips. This usage may possibly be through the form of shared autonomous vehicles (SAVs) or any other form of usage such as automated public transit or rideshare systems.

Respondents were also queried on their most preferred activity while riding in an autonomous vehicle. Results from Table 3-8 indicate that a large majority of respondents (31%) prefer to be alert and watch the road while riding in an autonomous vehicle. Roughly one-fifth (22%) of the respondents would prefer to relax and watch the outside view while smaller shares would most likely engage in reading (12%), phone calls/text messages (6%), sleep/nap (7%) or work/participate in a teleconference (6%). There aren't many gender-level differences in activities inside an autonomous vehicle of particular interest with current data. However, at a generational-level, it can be seen that larger shares of older respondents prefer to be alert and watch the road or relax and enjoy the outside view while riding in an autonomous vehicle, relative to their younger counterparts. Older respondents seem less and less likely to engage in other activities, perhaps indicating their preferences for a similar sized vehicles in the future as well (refer Table 3-8 for results).

When queried on the possibility of purchasing a differently sized vehicle then the one they currently own, a majority of the respondents (78%) indicated that they would be looking to purchase a similarly sized vehicle to the one they currently own, even with the introduction of autonomous vehicles in the market. This finding is interesting considering recent discussion on the plethora of activities that could be undertaken while riding in an autonomous vehicle, thereby impacting future vehicular sizes. Gender-based analyses reveals only marginal differences between males and females when it comes to future vehicular sizes. However, across the four generations, it is seen that a significantly higher share of millennials (24%) seem to prefer a bigger sized vehicle for their future purchase with the introduction of AVs, than their older cohorts. It is plausible that a good share of these younger cohorts foresee additions to their families (such as single respondents starting a family, families expanding etc.) and would generally prefer a larger sized vehicle in the future. It is also possible that these respondents foresee the benefits of more productive travel times and feel the need for bigger-sized vehicles in order to undertake the full gamut of possible activities while riding in an autonomous vehicle. While the needs for bigger-sized vehicles are along expected lines, it is not entirely clear why a section (small yet, a significant share) of respondents foresee investing in smaller-sized vehicles. Further research would be required to understand this phenomenon.

Results also revealed the potential impact of autonomous vehicles on future residential locations. A significant share of respondents (60%) do not foresee the possibility of moving further for better and more affordable housing once autonomous vehicles are available in the market for their use. However, in comparison to women, nearly twice the share of men (41% v/s 22%) think they are likely to move farther for better, affordable housing with the introduction of autonomous vehicles. Results also indicate that twice the shares of women, in comparison to men, are unsure of their future residential location shifts with the introduction of autonomous vehicles. Residential location shifts are often long-term decisions, taken collectively at a family-level (wherever applicable) and the uncertainty levels indicated by women, are perhaps a reflection of this fact.

When the data is segregated across the four generations, it can be seen that there are subtle differences in opinion on future residential locations with the introduction of autonomous vehicles. A significantly higher share of millennials are likely to move farther for better, affordable housing with the introduction of autonomous vehicles, relative to their older counterparts. Additionally, there is a constant increase in the shares of respondents who are unlikely to move farther than their current residences as respondents' age. There could be several reasons attributed to this – older generations are probably more stable with their housing and employment situation (due to a greater level of advancement in their ages) than millennials. Additionally, older respondents may not be foreseeing the benefits of a tradeoff between more affordable housing and a possible increase in travel time (even though this travel time could be more productive, than before) simply because some of these respondents may find it onerous to relocate from their current locations.

Despite there being some uncertainty, close to one-fifth (19%) of the respondents are likely to use the self-parking feature in their autonomous vehicles, every time. Higher shares of females expressed interest in using the self-parking feature over their male counterparts, indicating their preferences to possibly reduce the time spent in parking their vehicle (and achieve savings in their overall commute as well). Similarly, the younger demographic seem more interested in using this feature every time in their autonomous vehicles, possibly for similar reasons as mentioned above. Older generations exhibit more reluctance to use the self-parking feature, possibly indicating their apprehensions over this technology.

CHAPTER 4: CONSUMERS' PERCEPTIONS AND INTENDED ADOPTION OF AUTONOMOUS VEHICLES

4.1 Background and Motivation

Not all technologies that have been in the limelight are immediately welcomed into the society by the consumers. History of technology adoption shows that consumers' attitudes towards new technologies follow a cycle of initial apprehension and/or resistance, gradual adaptation, and then eventual assimilation of this new technology into the society (Thierer, 2013). But for a small segment of early adopters, including technology enthusiasts and visionaries, the majority of consumers remain close-minded about the new technology (Moore, 2002; Heffner et al., 2007). On the other hand, some individuals are uncomfortable with technological change and uncertainty and remain skeptical with their adoption decisions (Edison and Geissler, 2003). Technologies that are originally viewed as either intrusive or unrealistic often become not just accepted but become essential with time (Thierer & Hagemann, 2014).

Previous research in technology adoption shows that new technology suffers from the barriers of lack of knowledge by potential adopters, high initial costs, and low-risk tolerance (Agarwal and Prasad, 1998). Consumers' perceptions of risk are based on experience, emotions, the media, and other non-technical sources (Sjoberg, 1998). Therefore, emerging vehicle technologies such as autonomous vehicles must overcome not only the technological barriers but also the social issues related to the consumers to achieve commercial success. Past studies state expected benefits such as enhanced safety (NHTSA, 2014), improved fuel efficiency, and reductions in traffic and carbon emissions (Intel, 2013). On the other hand, system/equipment failure, privacy (Seapine Software, 2014; Schoettle & Sivak, 2014), driving skill degradation (Cummings & Ryan, 2013), liability and legality (Schoettle & Sivak, 2014) are seen as major deterrents to smooth adoption of autonomous vehicles.

Research on intended adoption shows that males, on average, are more interested in adopting autonomous vehicles while females have more concerns about riding and purchasing autonomous vehicles (J.D. Power, 2012; Schoettle & Sivak, 2014). Other factors such as younger ages, higher education levels, and residing in urban or suburban areas were found to be positively correlated with higher interests in autonomous vehicle technology (J.D. Power, 2012; Pew Research Center, 2014). The literature also reveals that the intended adoption of autonomous vehicles is rather sensitive to economic incentives (Howard & Dai, 2014; Kyriakidis et al., 2014). For instance, respondents' interests in purchasing autonomous vehicles increased remarkably when cheaper car insurance was promised (Carinsurance.com, 2013; Insurance.com, 2014) and declined sharply after the cost for autonomous vehicle technology was disclosed (J.D. Power, 2012).

As seen from discussions above, the research on understanding intended adoption of autonomous vehicles provides only a descriptive, univariate analysis of demographic/attitudinal differences without going in-depth into the influence of individual-level attributes beyond socio-demographics. Additionally, there is a dearth of peer-reviewed academic literature on how consumers' perceptions regarding the potential benefits and concerns with autonomous vehicles influence their intended adoption (or non-adoption). Not just that, most conventional adoption studies assume that the factors that influence adoption (or non-adoption) of autonomous vehicles remain the same across all kinds of consumer demographics. The current research addresses these gaps in the literature by untangling the influence of multiple agents (such as socio-demographics, current travel characteristics, and crash history) on each consumer market segments' intended adoption of autonomous vehicles when they become available in the market.

4.2 Objectives

Since this study involves multiple stages, the following objectives are set out:

I. Identify the different market segments with autonomous vehicle consumers

II. Determine the factors influencing the probability of a consumer belonging to a particular autonomous vehicle consumer market segment

III. Identify the influence of respondent socio-demographics and other behavioral characteristics on their intended adoption of autonomous vehicles across each consumer market segment

The first objective is achieved by conducting a two-step cluster analysis to uncover the various market segments of autonomous vehicle customers. These market segments (or clusters, used interchangeably in this document) help the analyst to identify the different categories of consumers based on their perceptions of the benefits and concerns with autonomous vehicles. Once this is achieved, a multinomial logit model is then estimated to determine the probability of a consumer belonging to a particular market segment. While this information enables the analyst to target specific market segments of autonomous vehicle consumers based on socio-demographics and other behavioral characteristics, it does not provide an accurate picture on their intended adoption of autonomous vehicles across these market segments. To fulfill this, econometric models are estimated for understanding the factors influencing the intended adoption of autonomous vehicles for each consumer market segment.

4.3 Analyzing Consumers' Perceptions of Autonomous Vehicles

This section details the efforts in understanding consumers' perceptions of autonomous vehicles.

4.3.1 Data

To determine the factors that may influence the probability of a consumer belonging to a particular autonomous vehicle consumer market segment, a web-based survey was conducted to target population groups. The first targeted group is the students, faculty, and staff of the University of South Florida (USF) system (all three campuses – Tampa, St. Petersburg, and Sarasota-Manatee), and the second targeted group is members of American Automobile Association (AAA) South. These surveys were disseminated for data collection during April and June 2015, respectively. Both surveys collected a wide range of data relating to socioeconomics, and various behavioral characteristics (such as commuting behavior, vehicle crash experience, and vehicle inventory).

Using data collected from both the target groups, a total of 2477 observations were available to study people's likelihood of belonging to a particular autonomous vehicle consumer market segment. Table 4-1 provides summary statistics for some key elements of the sample. This table shows that 28.8% of those surveyed were millennials and roughly one-third (33.1%) of the respondents possessed a graduate degree. 15% of the respondents belonged to households with an annual income more than $150,000, and 16% traveled a one-way commute distance in excess of 20 miles. However, a majority of the respondent households recently purchased/leased a new vehicle (54%). Lastly, around one-fifth of the respondents (18%) have been involved in a crash with a major injury.

Table 4-1 Descriptive Statistics of the Variables of Interest in Understanding the Probability of a Consumer Belonging to a Particular Autonomous Vehicle Market Segment

Variable Description	**Mean**	**Standard Deviation**
Male Respondent Indicator (1 if respondent is male, 0 otherwise)	0.536	0.499
University Respondent Indicator (1 if respondent is classified as a university respondent, 0 otherwise)	0.269	0.442
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise)	0.288	0.453
Baby Boomer Indicator (1 if respondent is classified as a baby boomer, 0 otherwise)	0.300	0.458
Generation X Indicator (1 if respondent is classified as a generation X respondent, 0 otherwise)	0.115	0.320
Graduate Indicator (1 if respondent's highest educational qualification is a graduate degree, 0 otherwise)	0.331	0.471
Non-Commuter Indicator (1 if respondent does not undertake a commute trip, 0 otherwise)	0.225	0.418
Drive Alone Commuter Indicator (1 if respondent typically drives alone to their commute, 0 otherwise)	0.675	0.468
Very High Licensed Driver Household Indicator (1 if respondent is a member of a household that has 3 or more licensed drivers, 0 otherwise)	0.084	0.278
High Income Household Indicator (1 if respondent is a member of a household with an annual income $150,000 or more, 0 otherwise)	0.145	0.352
High Commute Distance Indicator (1 if respondent travels a one-way distance of 20 miles or more for their commute, 0 otherwise)	0.161	0.368
High Commute Time Indicator (1 if respondent spent a total of 60 minutes or more on an average for their one-way commute, 0 otherwise)	0.046	0.209
Medium Overall Daily Travel Time Indicator (1 if respondent travels 45 minutes or less on an average for their total daily travel, 0 otherwise)	0.462	0.499
High Parking Time Indicator (1 if respondent spent 10 or more minutes on an average towards finding a parking spot during their commute, 0 otherwise)	0.215	0.411
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns more than three vehicles, 0 otherwise)	0.084	0.278
Vehicle Purchase Category Indicator (1 if respondent most recently purchased or leased a new vehicle, 0 otherwise)	0.542	0.498
Major Injury Severity Indicator (1 if the respondent was involved in one or more crashes, and respondent-involved crashes resulted in major injury, 0 otherwise)	0.176	0.381

In addition to socio-demographics and other behavioral information, respondents' opinions were also sought on potential benefits and concerns with autonomous vehicles (see Table 4-2). For their views on the benefits of autonomous vehicles, respondents were asked for their opinions on a five-point Likert scale ranging from *Extremely Unlikely* to *Extremely Likely*. Respondents indicated the three main benefits of autonomous vehicles – (1) More productive use of travel time, (2) Less stressful driving experience, and (3) Fewer traffic crashes and increased roadway safety.

Respondents' concerns with autonomous vehicles elicited on a five-point Likert scale ranging from *Not at all Concerned* to *Extremely Concerned*. Respondents indicated the three main concerns with autonomous vehicles – (1) System/equipment failure, (2) Performance in (or response to) unexpected traffic conditions, and (3) Giving up control of the steering wheel to the vehicle.

Table 4-2 Descriptive Statistics of Consumer's Opinions on the Proposed Benefits, and Concerns with Autonomous Vehicles

Description of Autonomous Vehicles Perception Variables	**Extremely Unlikely**	**Unlikely**	**Unsure**	**Likely**	**Extremely Likely**
Potential Benefit - Fewer traffic crashes and increased roadway safety	6.8%	11.7%	22.2%	36.5%	22.8%
Potential Benefit - Less stressful driving experience	8.4%	15.3%	18.9%	34.0%	23.4%
Potential Benefit - Less traffic congestion	12.3%	28.1%	25.6%	21.9%	12.2%
Potential Benefit - More productive (than driving) use of travel time	6.6%	13.5%	22.1%	31.2%	26.5%
Potential Benefit - Increased fuel efficiency	5.7%	13.4%	27.4%	38.0%	15.6%
Potential Concern - Safety of the vehicle occupants and other road users such as pedestrians, bicyclists.	5.0%	14.0%	14.8%	37.8%	28.3%
Potential Concern - System/equipment failure or AV system hacking	2.6%	11.3%	15.2%	34.4%	36.5%
Potential Concern - Performance in (or response to) unexpected traffic situations, poor weather conditions	3.1%	10.0%	15.5%	35.6%	35.8%
Potential Concern - Difficulty in determining who is liable in the event of a crash	8.6%	16.0%	21.3%	28.0%	26.1%
Potential Concern - Privacy risks from data tracking on my travel locations and speed	9.9%	16.7%	15.4%	27.4%	30.7%
Potential Concern - Loss in human driving skill over time	11.2%	17.2%	13.2%	30.8%	27.6%

4.3.2 Methodology

As previously discussed, a two-step procedure has been employed for enhancing our understanding of the various autonomous vehicle consumer market segments based on their perceptions of the benefits and concerns. Two-step cluster analysis is applied to identify the different autonomous vehicle consumer market segments that can be unearthed from the dataset. Then, econometric models (namely a multinomial logit model in this case) are used to determine how consumer attributes such as socio-demographics (respondent and household-level characteristics), current travel behavior, and crash history significantly influence the probability of them being in the specific market segments as defined by the cluster analysis.

4.3.2.1 Cluster Analysis

Cluster analysis is a multivariate technique widely used to identify structures based only on the information found in the data (Anderberg, 1973). Its primary objective is to restructure the data into groups, with a high degree of association within the elements of each group (Tan, 2006). Cluster analysis is used as an exploratory technique to uncover respondent subgroups with seemingly diverse characteristics, to derive insights on the decision-making processes of business entities and/or individuals (Guo et al., 2016). This technique has been employed in transportation literature for the last several decades.

Chang et al. (1992) used cluster analysis and discriminant analysis to determine the impact of commuter driving behavior on the rapid growth in suburban populations. Ng et al. (1998) employed cluster analysis to unearth groups of private and commercial drivers based on how much importance they placed on trip factors that influenced their commute trips. Guo et al. (2016) employed cluster analysis to understand the correlation between truck freight carriers' operational and behavioral characteristics, and the factors that foster/impede their willingness to collaborate with rail freight carriers. A two-step cluster analysis is preferred over hierarchical or portioning cluster analysis due to its ability to simultaneously handle both categorical and continuous as well as its capacity to be flexible in defining the required number of clusters (Chui et al., 2001). Following these works, a two-step cluster analysis was employed for identifying the various autonomous vehicle consumer market segments. The eleven variables (factors) determined previously through factor analysis were used for conducting the cluster analysis in this study.

The two-step cluster analysis identified consumer market segments based on the factors influencing the adoption (or non-adoption) of autonomous vehicles. These factors comprise of five potential benefits, and six potential concerns with autonomous vehicles. These benefits include fewer traffic crashes and increased roadway safety, less stressful driving experience, less traffic congestion, more productive use of travel time, and increased fuel efficiency. The potential concerns include safety of the vehicle occupants and other road users, system/equipment failure, performance in unexpected traffic situations, difficulty in determining liability in the event of a crash, privacy risks from data tracking, and loss in human drying skill over time.

Based on the results from the two-step cluster analysis procedure employed using SPSS 23 (IBM Corp., 2014), four different autonomous vehicle consumer market segments are obtained. These market segment centers represent a mathematical average of responses for members within each market segment. In order to understand the intended adoption potential of these market segments, the average scores obtained for intended adoption for said clusters were correlated along with the scores obtained for the perception variables under each cluster. The findings are as shown in Table 4-3.

The first market segment (n=513, 19.3%) identified by the two-step cluster analysis, the benefits-dominated segment, included consumers who foresee benefits with the introduction of autonomous vehicles. Respondents under this market segment believe that the proposed benefits of autonomous vehicles such as *fewer traffic crashes and increased roadway safety*, *less stressful driving experience*, more productive use of travel time, increased fuel efficiency, and *less traffic congestion* are more likely to occur with the introduction of autonomous vehicles. It is likely that respondents who belong to this market segment are usually early adopters of new technology. It was also seen that their positive outlook towards potential benefits with autonomous vehicles also reflected on their intended adoption of autonomous vehicles as well, evidenced by their high adoption score.

Table 4-3 Segment Means for Each Respondent Group Based on Perception of Benefits and Concerns of Autonomous Vehicles (Bold Numbers Indicate that the Majority of Respondents in this Segment Consider this Factor Likely or Extremely Likely)

Description of Autonomous Vehicles Perception Variables	**Benefits-Dominated Cluster** (N=513)	**Uncertain Cluster** (N=732)	**Well-Informed Cluster** (N=811)	**Concerns-Dominated Cluster** (N=602)
Potential Benefit - Fewer traffic crashes and increased roadway safety	**4.65**	3.08	**4.14**	2.47
Potential Benefit - Less stressful driving experience	**4.62**	2.89	**4.21**	2.27
Potential Benefit - Less traffic congestion	**4.18**	2.46	3.35	4.89
Potential Benefit - More productive (than driving) use of travel time	**4.57**	2.97	**4.24**	2.57
Potential Benefit - Increased fuel efficiency	**4.21**	3.07	3.85	2.69
Potential Concern - Safety of the vehicle occupants and other road users such as pedestrians, bicyclists.	2.35	3.43	**4.26**	**4.43**
Potential Concern - System/equipment failure or AV system hacking	2.77	3.48	**4.4**	**4.73**
Potential Concern - Performance in (or response to) unexpected traffic situations, poor weather conditions	2.82	3.49	**4.44**	**4.64**
Potential Concern - Difficulty in determining who is liable in the event of a crash	2.46	3.15	3.63	**4.52**
Potential Concern - Privacy risks from data tracking on my travel locations and speed	2.68	3.07	3.67	**4.59**
Potential Concern - Loss in human driving skill over time	2.46	3.34	3.45	**4.49**
Likelihood of adopting autonomous vehicles when they become available in the market	**4.24**	2.54	3.39	1.74

The second market segment (n=732, 27.5%), the uncertain segment, included consumers who are skeptical about both the potential benefits as well as the potential concerns with autonomous vehicles. It is highly likely that this segment is relatively unexposed towards the discussions and discourse on emerging vehicle technologies such as autonomous vehicles.

Alternatively, it is also possible that this segment is usually skeptical about emerging technologies and often less likely to feature among the list of early adopters. Their adoption scores tend towards the unlikely range, perhaps unsurprising given their skepticism.

The third market segment (n=811, 30.5%), the well-informed segment, included consumers who are equally aware of the potential benefits and concerns with autonomous vehicles. While consumers in this market segment feel that the proposed benefits such as *more productive use of travel time*, *less stressful driving experience*, and *fewer traffic crashes* are likely to occur, they are also equally concerned about issues such as *performance of the AV in unexpected traffic situations*, *possible system/equipment failure*, and other safety-related concerns with the introduction of autonomous vehicles. Their adoption scores tend towards the likely range most likely indicating a wait-and-watch approach before immersing themselves into the adoption process (see Table 4-3).

The final market segment (n=602, 22.6%), the concerns-dominated segment, consisted of consumers who are increasingly concerned about the potential issues with autonomous vehicles. Respondents under this market segment felt they would likely to be more concerned about *possible system/equipment failure*, *performance in unexpected traffic and weather conditions*, *privacy risks from data tracking*, *difficulty in determining liability in the event of a crash*, *loss in human driving skill over time*, and *safety of the vehicle occupants and other road users*. It seems that these concerns eventually influence their autonomous vehicle adoption decisions as well, as evidenced by their low mean intended adoption scores as shown in Table 4-3.

The two-step cluster analysis employed in this study reveals interesting insights on autonomous vehicle consumer market segments. Aside from the conventional benefits- and concerns-dominated market segments, the uncertain and the well-informed market segments create value in enhancing our understanding of the consumer demographics in a world with autonomous vehicles. This information would likely provide auto-manufacturers, and transportation professionals with market segments that provide different opportunities and challenges during market penetration of such technologies. Insights from this cluster analysis could also be used to devise different approaches to be adopted so as to prepare various consumer segments for a world with autonomous vehicles.

4.3.2.2 Multinomial Logit Model Structure

To determine the characteristics that make respondents more or less likely to belong to one of the identified autonomous vehicle consumer market segments, a multinomial logit model is estimated. For the multinomial logit analysis, we start by defining a function that determines market segment probabilities,

$$MS_{in} = \beta_n X_{in} + \varepsilon_{in},$$

where $\boldsymbol{MS_{in}}$ is a function determining the probability that respondent $\boldsymbol{i}$ will be classified in market segment $\boldsymbol{n}$, $\boldsymbol{X_{in}}$ is a vector of explanatory variables that affect the likelihood that respondent $\boldsymbol{i}$ will be classified in market segment $\boldsymbol{n}$, $\boldsymbol{\beta_n}$ is a vector of estimable parameters for market segment $\boldsymbol{n}$, and $\boldsymbol{\varepsilon_{in}}$ is an error term which is assumed to be generalized extreme value distributed (McFadden, 1981).

The most common extreme value distribution is the Type 1 distribution (also known as the Gumbel distribution) which has this special property that the maximums of randomly drawn values from the extreme value Type 1 distribution are also extreme value Type 1 distributed. The choice of extreme value Type 1 distribution is based on computational convenience, although the distribution is very similar to the normal distribution (Washington et al., 2011). The probability density function of the extreme value type I distribution is,

$$F(\varepsilon) = \eta EXP\big(-\eta(\varepsilon - \omega)\big) EXP\Big(-EXP\big(-\eta(\varepsilon - \omega)\big)\Big)$$

with corresponding density function

$$F(\varepsilon) = EXP\left(-EXP\big(-\eta(\varepsilon - \omega)\big)\right)$$

where η is a positive scale parameter, $\omega$is a location parameter (mode), and the mean is $\omega + 0.5772/\eta$.

To derive an estimable model based on the extreme value Type 1 distribution, following (McFadden, 1978; McFadden, 1981), with *I* denoting all possible outcomes for observation *n* and $P_n(i)$ being the probability of observation *n* having the discrete outcome *i* (*i ϵ I)*

$$P_n(i) = P\left(\boldsymbol{\beta}_i\boldsymbol{X}_{in} + \varepsilon_{in} \geq \max_{\forall I \neq i}(\boldsymbol{\beta}_I\boldsymbol{X}_{In} + \varepsilon_{In})\right)$$

The above equation leads to the mathematical structure known as the Multinomial Logit Model (MNL), which gives the choice probabilities of each observation as a function of the systematic portion of the utility of all other observations,

$$P_n(i) = \frac{EXP[\boldsymbol{\beta}_i\boldsymbol{X}_{in}]}{\sum_{\forall I} EXP(\boldsymbol{\beta}_I\boldsymbol{X}_{In})}$$

For estimation of the parameters (**β**'s) by maximum likelihood, the log-likelihood function is

$$LL = \sum_{n=1}^{N}\left(\sum_{i=1}^{I}\delta_{in}\left[\beta_i X_{in} - LN\sum\nolimits_{\forall I} EXP(\beta_I X_{In})\right]\right)$$

where *I* is the total number of outcomes, δ_{in} is defined as being equal to 1 f the observed discrete outcome for observation *n* is *I* and zero otherwise.

4.3.3 Model Estimation Results

To determine the characteristics that increase or decrease respondents' probability of belonging to one of the identified market segments, a multinomial logit model is estimated. It was hypothesized that respondent's likelihood of belonging to one of the identified market segments was different among males and females. Previous literature has shown significant gender-level differences on the factors influencing technology adoption and risk taking in transportation-related decisions (Abay and Mannering, 2016). To test if separate statistical models should be estimated for male and female respondents, a likelihood ratio test is conducted with the test statistic $X^2 = -2[LL(\boldsymbol{\beta}_{total}) - LL(\boldsymbol{\beta}_{male}) - LL(\boldsymbol{\beta}_{female})]$ where the $LL(\boldsymbol{\beta}_{total})$ is the log-likelihood at convergence of the model using all respondents (both male and female respondents), $LL(\boldsymbol{\beta}_{male})$ is the log-likelihood at convergence using only male respondents, and $LL(\boldsymbol{\beta}_{female})$ is the log-likelihood at convergence using only female respondents. In this case, we could not reject the null hypothesis that the two survey groups were the same at reasonable confidence levels.

A likelihood ratio test was also conducted to determine if there were significant differences between the University of South Florida and American Automobile Association (AAA) respondents. Similar to the previous case, we could not reject the null hypothesis that the two survey groups were the same at reasonable confidence levels. Thus we do not estimate separate models for these two survey groups.

4.3.4 Discussion of Estimation Findings

Being male, on average, increases the probability of belonging to the benefits-dominated market segment relative to their female counterparts (as shown in Table 4-4). Past literature has shown gender-level decisions in risk-taking in transportation-related decisions (Abay and Mannering, 2016). Additionally, males have been more prone to be early adopters of new technology in comparison to their female counterparts (Kennedy and Funk, 2016). Additionally, current university respondents (1 if the respondent is classified as a university respondent, 0 otherwise) have a higher probability of belonging to the benefits-dominated market segment than their non-university counterparts.

Comparing across generations (with the great generation as the base), it can be seen that millennials (respondents who are less than 35 years of age) have a higher probability of belonging to the well-informed markets segment, relative to the senior counterparts (respondents over the age of 65 years). Millennials are a significant demographic in determining the course of future technology adoption as they are the largest living generation (Fry, 2016) and are set to dominate the future discussions and discourse on adoption of new technologies. These findings are in line with previous literature that talks about millennial attitudes towards the adoption of emerging technologies (Smith, 2011; Smith, 2013; Anderson, 2015).

Model results from Table 4-4 also show that Gen-X-ers (respondents who are between 35 and 49 years of age) have a lower probability of being in the uncertain market segment relative to seniors. On the other hand, baby boomers (respondents who are aged between 50 and 64 years) have a higher probability of belonging to the concerns-dominated market segment than their senior counterparts (respondents who are 65 years or older). Although any data on generational preferences for autonomous vehicle adoption are absent, past literature shows that Gen-X-ers affinity for technology in comparison to their older counterparts (Boe, 2013). Therefore, it is unsurprising to see them being more certain about potential benefits and concerns with autonomous vehicles.

Respondents with a graduate degree and those who drove alone for their commute trips are less likely to belong to the concerns-dominated market segment. It is probable that a higher education and higher annual household income expose respondents to greater discussions and discourse on the benefits of autonomous vehicles. On the other hand, non-commuters (1 if the respondent does not undertake a commute trip, 0 otherwise) have a higher probability of being uncertain about the benefits and concerns with autonomous vehicles, which might ultimately impact their adoption of such technologies when they become available in the market (as shown in Table 4-4). At a household level, those with a very high number of licensed drivers (1 if the respondent is a member of a household that has 3 or more licensed drivers, 0 otherwise) have a lower probability of belonging to the uncertain market segment. Similarly, households with an annual income $150,000 or more, 0 otherwise have a lower probability of belonging a concerns-dominated market segment.

Current vehicle ownership and vehicle purchase inventories seem to have an effect on the likelihood of belonging to a particular market segment. While households that own more than three vehicles have a higher probability of belonging to a concerns-dominated market segment, those that most recently purchased or leased a new vehicle have a lower probability of belonging to the concerns-dominated market segment. At the outset, these results look counter-intuitive. On closer look, however, it is likely that respondents in households that own a large number of vehicles are likely entrenched in a driving culture. Therefore, they are less likely to be enthused about a technology that takes the pleasure of driving away the driver and are likely to be skeptical of its benefits. Additionally, most new vehicles are equipped with advanced safety and automation features that are likely to play a vital role in reducing consumers' skepticism about the potential issues with emerging technologies.

Several model results show the impact of current travel characteristics on respondents' probability of belonging to a particular market segment (see Table 4-4). For example, if a respondent travels an average one-way distance of 20 miles or more for their commute, or travel 45 minutes or less on average, for their total daily travel have a higher probability of belonging to a benefits-dominated market segment. Meanwhile, respondents who spend a total of 60 minutes or more, on average, for their one-way commute have a higher probability of belonging to the well-informed market segment. On the other hand, respondents who drive alone for their commute trips have a lower probability of belonging a concerns-dominated market segment. From a current travel perspective, it is interesting to see how engaging in more travel seems to possibly ease up any skepticism on emerging vehicle technologies such as autonomous vehicles.

Lastly, injuries suffered in the respondent involved crashes have a significant impact on the likelihood of belonging to a certain market segment. Respondents who were involved in crashes that resulted in major injuries have a lower probability of belonging to the concerns-dominated market segment. It is likely that these respondents, due to their past experiences, enjoy higher levels of awareness and exposure on safety and automation features that are aimed at reducing fatalities and enhancing the perception of safety in driving.

The insights obtained from this study can be used to target specific market segments to improve their perceptions about autonomous vehicles. This targeted marketing can also gauge public sentiments towards their eventual adoption of these technologies. However, the factors that influence the adoption of autonomous vehicles is still not completely clear to the analyst. The current study has only conducted a correlative analysis of the cluster-wide average scores for all the perception variables and the mean scores for intended adoption of autonomous vehicles based on those consumer market segments. The current study employs econometric modeling approaches in order to get a better understanding of the multiple influences on the intended adoption of autonomous vehicles. The next section details the efforts undertaken in this regard.

Table 4-4 Multinomial Logit Model for Predicting the Probability of Belonging to a Particular Market Segment Based on a Two-Step Cluster Analysis of Consumers' Perceptions of Potential Benefits & Concerns with Autonomous Vehicles (T-statistic in Parenthesis)

Variable Description	**Estimated Parameter (t statistic)**	Marginal Effects by segment			
		Benefits Dominated	**Uncertain**	**Well Informed**	**Concerns Dominated**
Factors for the benefits-dominated market segment					
Male Respondent Indicator (1 if respondent is male, 0 otherwise)	0.361 (3.33)	0.0543	-0.0183	-0.0210	-0.0150
University Respondent Indicator (1 if respondent is classified as a university respondent, 0 otherwise)	0.405 (3.04)	0.0610	-0.0205	-0.0236	-0.0168
High Commute Distance Indicator (1 if respondent travels a one-way distance of 20 miles or more for their commute, 0 otherwise)	0.445 (3.28)	0.0670	-0.0225	-0.0259	-0.0185
Medium Overall Daily Travel Time Indicator (1 if respondent travels 45 minutes or less on an average for their total daily travel, 0 otherwise)	0.250 (2.31)	0.0377	-0.0127	-0.0146	-0.0104
High Parking Time Indicator (1 if respondent spent 10 or more minutes on an average towards finding a parking spot during their commute, 0 otherwise)	0.223 (1.75)	0.0337	-0.0113	-0.0130	-0.0093
Factors for the uncertain market segment					
Constant	0.968 (7.41)				
Generation X Indicator (1 if respondent is classified as a generation X respondent, 0 otherwise)	-0.336 (-2.22)	0.0170	-0.0660	0.0276	0.0213
Very High Licensed Driver Household Indicator (1 if respondent is a member of a household that has 3 or more licensed drivers, 0 otherwise)	-0.274 (-2.32)	0.0139	-0.0537	0.0225	0.0173
Non-Commuter Indicator (1 if respondent does not undertake a commute trip, 0 otherwise)	0.257 (2.23)	-0.0130	0.0505	-0.0212	-0.0163
Factors for the well-informed market segment					
Constant	0.844 (6.77)				
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise)	0.603 (5.76)	-0.0352	-0.0486	0.1253	-0.0405
High Commute Time Indicator (1 if respondent spent a total of 60 minutes or more on an average for their one-way commute, 0 otherwise)	0.339 (1.69)	-0.0198	-0.0278	0.0704	-0.0228
Factors for the concerns-dominated market segment					
Constant	1.147 (7.23)				

Table 4-4 (Continued)

Baby Boomer Indicator (1 if respondent is classified as a baby boomer, 0 otherwise)	0.359 (3.31)	-0.0149	-0.0227	-0.0241	0.0617
High Income Household Indicator (1 if respondent is a member of a household with an annual income $150,000 or more, 0 otherwise)	-0.263 (-1.77)	0.0109	0.0166	0.0177	-0.0453
Graduate Indicator (1 if respondent's highest educational qualification is a graduate degree, 0 otherwise)	-0.239 (-2.21)	0.099	0.0151	0.0160	-0.0411
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns more than three vehicles, 0 otherwise)	0.353 (2.14)	-0.0147	-0.0223	-0.0237	0.0607
Vehicle Purchase Category Indicator (1 if respondent most recently purchased or leased a new vehicle, 0 otherwise)	-0.211 (-2.11)	-0.0147	-0.0223	-0.0237	0.0607
Drive Alone Commuter Indicator (1 if respondent typically drives alone to their commute, 0 otherwise)	-0.414 (-3.77)	0.0172	0.0262	0.0278	-0.0712
Major Injury Severity Indicator (1 if the respondent was involved in one or more crashes, and respondent-involved crashes resulted in major injury, 0 otherwise)	-0.295 (-2.21)	0.0123	0.0187	0.0199	-0.0508
Number of observations	2477				
Log-likelihood at zero	-3393.299				
Log-likelihood at convergence	-3319.390				

4.4 Understanding Intended Adoption of Autonomous Vehicles

While the previous section shed some light on determining the probability of a respondent belonging to an autonomous vehicle consumer market segment, it did not provide significant insights into understanding the factors that would influence their adoption of autonomous vehicles. Despite there being correlations between each autonomous vehicle consumer market segment (obtained through two-step cluster analysis) and their general attitudes towards adoption of these technologies, the previous section does not satisfactorily address the influencing factors contributing to adoption (or non-adoption). To address this, the current study employs econometric modeling techniques to estimate ordered probit models and understand consumers' likelihood of adopting autonomous vehicles when they become available in the market.

4.4.1 Data

The data for understanding the factors influencing the intended adoption of autonomous vehicles is adopted from the web-based multi-population surveys, the details of which are described earlier in this chapter (refer section 4.3.1 for more information and descriptive statistics). In order to extract cluster-based descriptive statistics of respondent socio-demographics and other behavioral characteristics, the data has been divided across the consumer market segments (see Table 4-5).

While a significant proportion of the benefits-informed consumer market segment (60%) comprise of males, it was interesting to note the higher percentage of women under the well-informed market segment (51%) and the lower percentages under the uncertain market segment (45%). Millennials constituted more than one-third of the well-informed market segment (38%) as well as the benefits-dominated market segment (33%). It was also seen that the highest percentage of concerns-dominated market segment comprised of baby boomers (37%) while the highest percentage of the uncertain market segment comprised of the great generation (40%). Almost equal shares of respondents from each consumer market segment belonged to low-income and high-income households respectively.

It was interesting but rather unsurprising to see that most the uncertain (27%) and the concerns-dominated (27%) market segments comprised of respondents who did not commute to work. On the other hand, a large section of the well-informed (72%) as well as the benefits-dominated (72%) market segments comprised of respondents who drove alone on their commute possibly indicating their higher amounts of exposure and preference towards new technologies. Interestingly, a larger share of the respondents from uncertain (65%) as well the concerns-dominated (63%) market segments spent 5 minutes or less parking their car during their commute trip. Lastly, it was also seen that more than one-fourth of the concerns-dominated market segment (28%) constituted of respondents whose households owned one or more vehicles.

4.4.2 Methodology

Several statistical/econometric modeling approaches are available to capture the influence of multiple factors that may affect the adoption (or non-adoption) of autonomous vehicles when they become available in the market. In the current study, we will estimate ordered probit models across the previously determined autonomous vehicle consumer markets segments (obtained from the two-step cluster analysis) – where the dependent variable (peoples' likelihood of adopting autonomous vehicles when they become available in the market) is modeled as ordinal data (where respondents indicate their likelihood to adopt as; *extremely unlikely*, *unlikely*, *unsure*, *likely*, *extremely likely*). An ordered probability modeling approach is appropriate to account for the ordering of the data, and the potential unequal differences among the ordinal categories in the dependent variable (Greene, 1997; Washington et al., 2011).

Table 4-5 Cluster-Based Descriptive Statistics of the Variables of Interest in Understanding Consumers' Likelihood of Adopting Autonomous Vehicles

	Benefits-Dominated (N=468)		**Uncertain (N=681)**		**Well-Informed (N=761)**		**Concerns-Dominated (N=567)**	
Variable Description	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Male Respondent Indicator (1 if respondent is male, 0 otherwise)	0.596	0.491	0.551	0.498	0.499	0.500	0.519	0.500
University Respondent Indicator (1, if respondent is a student, faculty, or staff at USF, 0 otherwise)	0.303	0.460	0.198	0.399	0.343	0.475	0.217	0.413
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise)	0.331	0.471	0.213	0.410	0.376	0.485	0.224	0.417
Baby Boomer Indicator (1 if respondent is classified as baby boomer, 0 otherwise)	0.280	0.449	0.292	0.456	0.268	0.443	0.367	0.482
Great Generation Indicator (1 if respondent is classified as belonging to the great generation, 0 otherwise)	0.248	0.432	0.395	0.489	0.246	0.431	0.289	0.454
White Respondent Indicator (1 if respondent is classified as white, 0 otherwise)	0.823	0.382	0.860	0.347	0.820	0.384	0.852	0.356
Hispanic/Black Respondent Indicator (1 if respondent is classified as Hispanic/black, 0 otherwise	0.105	0.306	0.100	0.300	0.105	0.307	0.078	0.268
Low Income Household Indicator (1 if respondent belongs to a household that earns an annual income less than $50,000, 0 otherwise)	0.267	0.443	0.257	0.437	0.294	0.456	0.272	0.445
High Income Household Indicator (1 if respondent belongs to a household that earns an annual income more than $100,000, 0 otherwise)	0.370	0.483	0.372	0.484	0.360	0.480	0.340	0.474
Two Person Household Indicator (1 if respondent belongs to a two person household, 0 otherwise)	0.453	0.498	0.526	0.500	0.472	0.500	0.489	0.500
Non-Commuter Indicator (1, if respondent does not commute to work, 0 otherwise)	0.175	0.381	0.273	0.446	0.181	0.386	0.266	0.442
Drive Alone Commuter Indicator (1 if respondent usually drives alone for his commute trip, 0 otherwise)	0.729	0.445	0.639	0.481	0.715	0.452	0.621	0.486

Table 4-5 (Continued)

Short Commute Distance Indicator (1 if respondent travels a one-way distance less than 5 miles for their commute, 0 otherwise)	0.182	0.386	0.170	0.376	0.205	0.404	0.134	0.341
Long Commute Time Indicator (1 if respondent travels 45 minutes or more one-way for their commute, 0 otherwise)	0.135	0.342	0.103	0.304	0.142	0.349	0.106	0.308
Total Daily Travel Time Indicator (1 if respondent travels less than 30 minutes every day for all their trips, 0 otherwise)	0.263	0.441	0.261	0.440	0.242	0.428	0.259	0.439
Total Daily Travel Time Indicator (1 if respondent travels more than 90 minutes every day for all their trips, 0 otherwise)	0.150	0.357	0.103	0.304	0.154	0.361	0.109	0.312
Low Parking Time Indicator (1 if respondent spends 5 minutes or less in order to park their vehicle, 0 otherwise)	0.577	0.496	0.648	0.478	0.548	0.498	0.626	0.484
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns zero vehicles, 0 otherwise)	0.092	0.289	0.056	0.230	0.085	0.280	0.041	0.197
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns more than one vehicle, 0 otherwise)	0.244	0.430	0.244	0.430	0.214	0.411	0.277	0.448
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns three or more vehicles, 0 otherwise)	0.073	0.260	0.081	0.273	0.074	0.261	0.113	0.317
Recent Vehicle Purchase Indicator (1 if respondent recently purchased or leased a new vehicle, 0 otherwise)	0.536	0.499	0.589	0.492	0.519	0.500	0.522	0.500
Recent Vehicle Purchase Indicator (1 if respondent recently purchased a used vehicle, 0 otherwise)	0.368	0.483	0.352	0.478	0.392	0.488	0.430	0.496
Crash Indicator (1 if respondent has been involved in a traffic crash in the past, 0 otherwise)	0.741	0.438	0.706	0.456	0.735	0.442	0.709	0.455

An ordered probability model is derived by defining an unobserved variable, z, which is used as a basis for modeling the ordinal ranking of data. This unobserved variable is specified as a linear function,

$$z_n = \boldsymbol{\beta}\mathbf{X}_n + \varepsilon_n$$

where **X** is a vector of explanatory variables determining the discrete ordering for observation n, $\boldsymbol{\beta}$ is a vector of estimable parameters, and ε is a disturbance term. Using this equation, observed ordinal data, y_n, are defined as (with 1 = *extremely unlikely*, 2 = *unlikely*, 3 = *unsure*, 4 = *likely*, and 5 = *extremely likely*),

$$\begin{aligned} y_n &= 1 \text{ if } z_n \le \mu_0 \\ &= 2 \text{ if } \mu_0 < z_n \le \mu_1 \\ &= 3 \text{ if } \mu_1 < z_n \le \mu_2 \\ &= 4 \text{ if } \mu_2 < z_n \le \mu_3 \\ &= 5 \text{ if } z_n \ge \mu_3, \end{aligned}$$

where μ's are estimable parameters (referred to as thresholds) that define y_n and are estimated jointly with the model parameters $\boldsymbol{\beta}$. The estimation problem then becomes one of determining the probability of the five specific ordered responses for each observation n. This is done by assuming on the distribution of ε_n in Equation 1. If ε_n is assumed to normally distributed across observations an ordered probit model results (alternatively, if ε_n is assumed to logistic distributed an ordered logit model results). Note that without loss of generality μ_0 can be set equal to zero requiring estimation of three thresholds, μ_1, μ_2, and μ_3.

Assuming the disturbance terms are normally distributed (Washington et al., 2011), the ordered category selection probabilities can be written as (removing subscripting n for notational convenience),

$$P(y = 1) = \Phi(-\boldsymbol{\beta}\mathbf{X})$$
$$P(y = 2) = \Phi(\mu_1-\boldsymbol{\beta}\mathbf{X}) - \Phi(-\boldsymbol{\beta}\mathbf{X})$$
$$P(y = 3) = \Phi(\mu_2-\boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_1-\boldsymbol{\beta}\mathbf{X})$$
$$P(y = 4) = \Phi(\mu_3-\boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_2-\boldsymbol{\beta}\mathbf{X})$$
$$P(y = 5) = 1 - \Phi(\mu_{I-1}-\boldsymbol{\beta}\mathbf{X}),$$

where $\Phi(.)$ is the cumulative normal distribution.

For model interpretation, a positive value of $\boldsymbol{\beta}$ implies that an increase in $\mathbf{X}$ will increase the probability of getting the highest response (*extremely likely*) and will decrease the probability of getting the lowest response (*extremely unlikely*), but to interpret the intermediate categories (to estimate the direction of the effects of the interior categories of *unlikely*, *unsure* and *likely*) and the probability effect of the any variable in the vector $\mathbf{X}$ on each outcome category, average marginal effects are computed at the sample mean as Equation 4 below (Washington et al., 2011).

$$\frac{P(y=n)}{\partial \mathbf{X}} = \left[\phi(\mu_{n-1} - \boldsymbol{\beta}\mathbf{X}) - \phi(\mu_n - \boldsymbol{\beta}\mathbf{X})\right]\boldsymbol{\beta},$$

where $P(y = n)$ is the probability of outcome n, μ represents the thresholds, and $\phi(.)$ is the probability mass function of the standard normal distribution. The computed marginal effects quantify the effect that a one-unit change of an explanatory variable will have on outcome category n's selection probability.

Finally, there is likely unobserved heterogeneity present in the data which would result in the effect of explanatory variables to vary across individual observations or groups of observations. To account for this possibility, in the transportation literature, researchers have used random parameters models, latent class (finite mixture) models, Markov switching models, or combinations of these approaches. Using a model structure that can potentially account for unobserved heterogeneity is important because constraining parameters to be fixed across observations when they vary across observations can lead to inconsistent, inefficient and biased parameter estimates (Mannering et al., 2016). In this study, the possibility of parameters varying across observations is considered by estimating a random parameters formulation with,

$$\boldsymbol{\beta}_i = \boldsymbol{\beta} + \varphi_i \text{ ,}$$

where $\boldsymbol{\beta}_i$ is a vector of observation parameters and φ_i is a randomly distributed term (for example, normally distributed term with mean zero and variance σ^2). Estimation of this random parameters formulation (wherever feasible) is done by simulated maximum likelihood estimation, and we will use a 200 Halton-draw sequencing approach for the simulation as is commonly done in the literature (Bhat, 2003; Anastasopoulos and Mannering, 2009).

4.4.3 Model Estimation Results

Respondents' likelihood to adopt autonomous vehicles is likely to be much different across the four consumer market segments. This is because, among other possible reasons, members of a particular market segment perceive the potential benefits and concerns with autonomous vehicles differently than members of another market segment. To test if separate statistical models should be estimated for the various consumer market segments, a likelihood ratio test is conducted with the test statistic $X^2 = -2[LL(\boldsymbol{\beta}_{total}) - LL(\boldsymbol{\beta}_{cluster1}) - LL(\boldsymbol{\beta}_{cluster2}) - LL(\boldsymbol{\beta}_{cluster3}) - LL(\boldsymbol{\beta}_{cluster4})]$ where the $LL(\boldsymbol{\beta}_{total})$ is the log-likelihood at convergence of the model using all respondents (from all four consumer markets segments), and $LL(\boldsymbol{\beta}_{cluster1})$, $LL(\boldsymbol{\beta}_{cluster2})$, $LL(\boldsymbol{\beta}_{cluster3})$, $LL(\boldsymbol{\beta}_{cluster4})$ are the log-likelihoods at convergence using only respondents clusters 1, 2, 3 and 4 respectively. This test statistic is χ^2 distributed with degrees of freedom equal to the difference in the number of parameters of both models. The value of X^2 is 703.77, and with 41 degrees of freedom, we are more than 99% confident that the null hypothesis that the four cluster respondents are the same, can be rejected. Thus, separate models are estimated for all the four clusters.

A likelihood ratio test was also conducted to determine if there were significant differences between the University of South Florida and American Automobile Association (AAA) respondents. In each individual market segment model, we could not reject the null hypothesis that the two survey groups were the same at reasonable confidence levels. Thus, we do not estimate separate models for these two survey groups.

Ordered probit models are estimated for all four clusters (i.e., the benefits-dominated market segment, the uncertain market segment, the well-informed market segment, and the concerns-dominated market segment). Parameters producing statistically significant standard deviations for their assumed distribution are treated as parameters that vary across the population (with each observation having its own parameter), and the remaining parameters are treated as fixed parameters because the standard deviations are not significantly different from zero (one parameter for all observations). Again, a log-likelihood ratio test was conducted to statistically compare the random parameters and the fixed parameters model for all the consumer market segments.

The likelihood ratio test statistic is calculated as $X^2 = -2[LL(\boldsymbol{\beta}_{random}) - LL(\boldsymbol{\beta}_{fixed})]$ where the $LL(\boldsymbol{\beta}_{random})$ is the log-likelihood at convergence of the random-parameter ordered probit model and the $LL(\boldsymbol{\beta}_{fixed})$ is the log-likelihood at convergence of the fixed-parameter ordered probit model. The test statistic X^2 is χ^2 distributed with degrees of freedom equal to the difference in the number of parameters of both fixed and random parameters models. For respondents from the benefits-dominated cluster, the value of χ^2 is 32.21, and with 15 degrees of freedom, we are more than 99% confident that the null hypothesis that the random- and fixed-parameters ordered probit models are equal can be rejected (thus justifying the use of the random parameters formulation).

Table 4-6 Ordered Probit Model Estimation of Consumers' Likelihood of Adopting Autonomous Vehicles across Different Market Segments

	Benefits-Dominated		Uncertain		Well-Informed		Concerns-Dominated	
Variable Description	**Estimated Parameter**	***t* statistic**	**Estimated Parameter**	***t* statistic**	**Estimated Parameter**	***t* statistic**	**Estimated Parameter**	***t* statistic**
Constant	4.537	9.95	0.510	5.11	2.758	11.08	0.426	2.58
Male Respondent Indicator (1 if respondent is male, 0 otherwise) *Standard deviation of parameter*	--	--	--	--	0.271 (*0.278*)	3.27 (*4.85*)	-0.253	-2.48
University Respondent Indicator (1, if respondent is a student, faculty, or staff at USF, 0 otherwise)	--	--	--	--			--	--
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise) *Standard deviation of parameter*	0.154 (*0.875*)	0.66 (*7.08*)	--	--	--	--	--	--
Baby Boomer Indicator (1 if respondent is classified as baby boomer, 0 otherwise) *Standard deviation of parameter*	0.440 (*1.403*)	1.97 (*8.91*)	--	--	-0.315	-2.61	--	--
Great Generation Indicator (1 if respondent is classified as belonging to the great generation, 0 otherwise)	-0.672	-2.90	--	--	-0.640	-4.99	0.289	2.42
White Respondent Indicator (1 if respondent is classified as white, 0 otherwise) *Standard deviation of parameter*	--	--	--	--	-0.087 (*0.325*)	-0.81 (*7.19*)	-0.273	-2.03
Hispanic/Black Respondent Indicator (1 if respondent is classified as Hispanic/black, 0 otherwise) *Standard deviation of parameter*	0.924 (*2.604*)	3.18 (*8.08*)	--	--	--	--	--	--
Low Income Household Indicator (1 if respondent belongs to a household that earns an annual income less than $50,000, 0 otherwise)	--	--	-0.316	-3.23	--	--	-0.221	-1.82
High Income Household Indicator (1 if respondent belongs to a household that earns an annual income more than $100,000, 0 otherwise) *Standard deviation of parameter*	0.420	2.70	--	--	0.147 (*0.642*)	1.69 (*9.15*)	--	--

Table 4-6 (Continued)

Two Person Household Indicator (1 if respondent belongs to a two person household, 0 otherwise) *Standard deviation of parameter*	--	--	--	--	-0.021 (*0.648*)	-0.25 (*10.42*)	--	--
Non-Commuter Indicator (1, if respondent does not commute to work, 0 otherwise) *Standard deviation of parameter*	0.362 (*1.259*)	1.79 (*7.19*)	--	--	--	--	--	--
Drive Alone Commuter Indicator (1 if respondent usually drives alone for his commute trip, 0 otherwise)	--	--	0.308	3.49	--	--	--	--
Short Commute Distance Indicator (1 if respondent travels a one-way distance less than 5 miles for their commute, 0 otherwise) *Standard deviation of parameter*	-0.390 (*1.501*)	-2.20 (*8.38*)	-0.187	-1.65	--	--	--	--
Long Commute Time Indicator (1 if respondent travels 45 minutes or more one-way for their commute, 0 otherwise) *Standard deviation of parameter*	0.523 (*1.578*)	2.35 (*6.70*)	--	--	0.262 (*0.537*)	2.14 (*4.78*)	--	--
Total Daily Travel Time Indicator (1 if respondent travels less than 30 minutes every day for all their trips, 0 otherwise)	--	--	0.210	2.20	--	--	--	--
Total Daily Travel Time Indicator (1 if respondent travels more than 90 minutes every day for all their trips, 0 otherwise)	--	--	--	--	--	--	-0.368	-2.21
Low Parking Time Indicator (1 if respondent spends 5 minutes or less in order to park their vehicle, 0 otherwise) *Standard deviation of parameter*	-0.008 (*1.463*)	-0.06 (*12.42*)	--	--	--	--	-0.332	-3.08
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns zero vehicles, 0 otherwise) *Standard deviation of parameter*	--	--	--	--	0.575 (*0.858*)	3.59 (*5.82*)	--	--
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns more than one vehicle, 0 otherwise)	-0.589	-3.93	--	--	--	--	--	--

Table 4-6 (Continued)

Vehicle Ownership Indicator (1 if respondent is a member of a household that owns three or more vehicles, 0 otherwise)	--	--	-0.162	-1.66	--	--	--	--
Recent Vehicle Purchase Indicator (1 if respondent recently purchased or leased a new vehicle, 0 otherwise)	0.717	4.98	--	--	0.279	3.24	--	--
Recent Vehicle Purchase Indicator (1 if respondent recently purchased a used vehicle, 0 otherwise)	--	--	--	--	--	--	-0.183	-1.80
Crash Indicator (1 if respondent has been involved in a traffic crash in the past, 0 otherwise)	0.261	1.73	--	--	--	--	--	--
Threshold, μ_1	1.282	4.19	0.671	16.65	0.948	11.60	0.732	13.86
Threshold, μ_2	2.676	8.05	1.451	28.03	1.715	18.62	1.491	18.01
Threshold, μ_3	5.360	13.91	2.600	27.35	3.366	28.68	2.159	15.63
Number of observations	468		681		761		567	
Log-likelihood at convergence	-488.478		-990.081		-1060.194		-631.104	

4.4.4 Discussion of Estimation Findings

Model estimation results are shown in Table 4-6 while the marginal effects across each consumer market segment are shown in Tables 4-7, 4-8, 4-9, and 4-10 respectively.

4.4.4.1 Intended Adoption under a Benefits-Dominated Market Segment

Gender was found to be insignificant in the adoption (or non-adoption) decisions concerning autonomous vehicles under a benefits-dominated market segment. From the marginal effect estimates shown in Table 4-7, Hispanic/black respondents in this market segment are more *extremely likely* to adopt autonomous vehicle when they become available in the market, relative to everyone else. Comparing across generations, belonging to the great generation (1 if respondent is of 65 years or above, 0 otherwise) in a benefits-dominated market segment increases the probability of being unlikely or extremely unlikely to adopt autonomous vehicles when they became available in the market, relative to Gen-X-ers (1 if respondent is between the ages of 35 and 49 years, 0 otherwise).

On the other hand, being a millennial (1 if respondent is under the age of 35 years, 0 otherwise) or a baby boomer (1 if respondent is between the ages of 50 and 64 years, 0 otherwise) in this market segment increases the probability of being extremely likely to adopt an autonomous vehicle when they become available in the market. However, all three of these variables mentioned above vary across the population indicating considerable heterogeneity among Hispanics/blacks, millennials, and baby boomers in a benefits-dominated market segment. These results are interesting to the analyst. Millennials are a significant demographic in determining the course of future technology adoption as they are the largest living generation (Fry, 2016) and are set to dominate the future discussions and discourse on adoption of emerging technologies.

Table 4-7 Marginal Effects for Significant Parameters in the Benefits-Dominated Market Segment

Variable Description	Marginal Effects				
	Extremely Unlikely	Unlikely	Unsure	Likely	Extremely Likely
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise)	-0.0000002	-0.000005	-0.003	-0.055	0.059
Baby Boomer Indicator (1 if respondent is classified as baby boomer, 0 otherwise)	-0.0000004	-0.00011	-0.008	-0.162	0.170
Great Generation Indicator (1 if respondent is classified as belonging to the great generation, 0 otherwise)	0.000003	0.0005	0.025	0.211	-0.236
Hispanic/Black Respondent Indicator (1 if respondent is classified as Hispanic/black, 0 otherwise) *Standard deviation of parameter*	-0.000004	-0.00012	-0.010	-0.345	0.355
High Income Household Indicator (1 if respondent belongs to a household that earns an annual income more than $100,000, 0 otherwise) *Standard deviation of parameter*	-0.0000004	-0.00012	-0.009	-0.152	0.161
Non-Commuter Indicator (1, if respondent does not commute to work, 0 otherwise)	-0.0000003	-0.00009	-0.007	-0.134	0.141
Short Commute Distance Indicator (1 if respondent travels a one-way distance less than 5 miles for their commute, 0 otherwise)	0.000001	0.00022	0.012	0.129	-0.141
Long Commute Time Indicator (1 if respondent travels 45 minutes or more one-way for their commute, 0 otherwise)	0.0000003	-0.00009	-0.008	-0.197	0.205
Low Parking Time Indicator (1 if respondent spends 5 minutes or less in order to park their vehicle, 0 otherwise)	0.0	0.000002	0.0002	0.003	-0.003
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns more than one vehicle, 0 otherwise)	-0.0000006	0.00017	0.012	0.214	-0.226
Recent Vehicle Purchase Indicator (1 if respondent recently purchased or leased a new vehicle, 0 otherwise)	-0.000001	-0.00033	-0.019	-0.246	0.266
Crash Indicator (1 if respondent has been involved in a traffic crash in the past, 0 otherwise)	-0.0000004	-0.00011	-0.007	-0.09	0.097

The baby boomers, on the other hand, are a generation of respondents who equate owning a car to independence (Ross, 2014). Previous studies have established their relative aversion towards new technologies (Rainie & Perrin, 2016). Therefore, the heterogeneity observed in a benefits-dominated market segment could be significant indicators for the need to avoid generalizations across generations. Annual household income was found to be an important indicator on adoption (or non-adoption) decisions regarding autonomous vehicles. High-income households (1 if respondent belongs to a household that earns an annual income more than $100,000, 0 otherwise) in benefits-dominated market segment are more *extremely likely* to adopt autonomous vehicles when they become available in the market (as shown in Table 4-7).

Several model results show the influence of current travel characteristics on consumers' adoption (or non-adoption) decisions of autonomous vehicles. For instance, it is interesting to note that respondents who do not commute to work are more *extremely likely* to adopt autonomous vehicles when they become available in the market. Likewise, respondents traveling 45 minutes or more one-way, on average, for their commute are more *extremely likely* to adopt autonomous vehicles. However, this behavior is not echoed by respondents who travel a one-way distance of 5 miles or less for their commute trips. Respondents who travel, on average, 5 miles or less for their commute in a benefits-dominated market segment are less *extremely likely* to adopt autonomous vehicles, relative to those that travel higher commute distances. There is considerable heterogeneity among observations as the variables depicting current travel characteristics in a benefits-dominated market segment are random parameters thereby indicating that not all commuters' adoption (or non-adoption) behaviors are similar.

Parking seems to have a complex effect on respondents' adoption (or non-adoption) of autonomous vehicles. Respondents in a benefits-dominated market segment, who spend 5 minutes or less in order to park their vehicle, are less *extremely likely* to adopt autonomous vehicles when they become available in the market. However, this parameter varies across observations showing considerable heterogeneity among the respondents. Vehicle ownership has an interesting influence on intended adoption of autonomous vehicles in a benefits-dominated market segment. If respondent belongs to a household that owns two or more vehicles, they are less *extremely likely* to adopt autonomous vehicles when they become available in the market. At the outset, these results look counter-intuitive. On closer look, however, it is likely that respondents in households that own a large number of vehicles are likely entrenched in a driving culture. Therefore, they are less likely to be enthused about adopting a technology that takes the pleasure of driving away the driver.

Additionally, respondents in a benefits-dominated, who recently purchased or leased a new vehicle are more *extremely likely* to adopt an autonomous vehicle when they become available in the market. Most new cars are fitted with advanced safety/automation features that make driver safer, and it's perhaps an influencing factor for such respondents to invest further in technologies that could potentially reduce crashes by 90% (NHTSA, 2014). Lastly, previous crash experience made respondents more *extremely likely* to adopt autonomous vehicles when they became available in the market – perhaps indicating an increased emphasis on safety in their driving.

4.4.4.2 Intended Adoption under an Uncertain Market Segment

In an uncertain market segment with little awareness of the potential benefits and concerns of autonomous vehicles, respondent gender, respondent age or ethnicity seem to have no influence on the intended adoption (or non-adoption) of these technologies. On the other hand, low-income households (1 if respondent belongs to a household that earns an annual income less than $50,000, 0 otherwise) in an uncertain market segment are more *unlikely* or *extremely unlikely* to adopt autonomous vehicles (as shown by the marginal effects in Table 4-8). It is quite possible that the additional costs involved in adopting emerging vehicle technologies such as autonomous vehicles prices out certain segments of the society. These results are consistent with recent findings from literature on willingness to pay for emerging vehicle technologies (Litman, 2017). It is likely that low-and medium-income households would mostly reap the benefits of autonomous vehicles in a shared environment.

Table 4-8 Marginal Effects for Significant Parameters in the Uncertain Market Segment

Variable Description	Marginal Effects				
	Extremely Unlikely	Unlikely	Unsure	Likely	Extremely Likely
Low Income Household Indicator (1 if respondent belongs to a household that earns an annual income less than $50,000, 0 otherwise)	0.103	0.023	-0.035	-0.072	-0.018
Drive Alone Commuter Indicator (1 if respondent usually drives alone for his commute trip, 0 otherwise)	-0.098	-0.024	0.032	0.071	0.019
Short Commute Distance Indicator (1 if respondent travels a one-way distance less than 5 miles for their commute, 0 otherwise)	0.061	0.014	-0.021	-0.043	-0.011
Total Daily Travel Time Indicator (1 if respondent travels less than 30 minutes every day for all their trips, 0 otherwise)	-0.067	-0.016	0.022	0.048	0.013
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns three or more vehicles, 0 otherwise)	0.052	0.013	-0.017	-0.037	-0.01

The influence of current travel characteristics on autonomous vehicle adoption (or non-adoption) is evident in an uncertain market segment as well. For instance, respondents who drove alone to work in this market segment are less *unlikely* or *extremely unlikely* to adopt an autonomous vehicle when they become available in the market. It is interesting that despite the uncertainty regarding potential benefits and concerns with autonomous vehicles, these respondents perhaps see driving to work as a highly onerous task and could very well consider investing in emerging vehicle technologies such as autonomous vehicles to negate the externalities.

Similarly, respondents who traveled less than 30 minutes every day for all their trips are less *unlikely* or *extremely unlikely* to adopt an autonomous vehicle. In contrast, respondents who travel less than 5 miles for their commute are more *unlikely* or *extremely unlikely* to adopt autonomous vehicles. These above-mentioned parameters show the rather complex relationship between current travel characteristics and the intended adoption (or non-adoption) possibilities of autonomous vehicles. Lastly, high vehicle ownership households (1 if respondent is a member of a household that owns three or more vehicles, 0 otherwise) in an uncertain market segment are more *unlikely* or *extremely unlikely* to adopt an autonomous vehicle. It could be due to their entrenchment in an ownership culture, as discussed earlier (refer section 4.4.4.1).

4.4.4.3 Intended Adoption under a Well-Informed Market Segment

Gender plays a significant role in adoption (or non-adoption) decisions of autonomous vehicles in a well-informed market segment. The marginal effects from table 4-9 show that being male, on average, increased the probability of being more *likely* or *extremely likely* to adopt an autonomous vehicle when they become available in the market. However, in a well-informed market segment, the effect of the variable was found to vary significantly across respondents (producing a statistically significant random variable), suggesting considerable heterogeneity across all the observations. Part of the reason for this statistically significant male/female difference could be due to men being less risk averse in well-informed market segment relative to women. These can be substantiated by advances in recent literature showing gender differences in risk-taking in transportation-related decisions (Abay and Mannering, 2016). Interestingly, university population respondents in a well-informed market segment are less *likely* or *extremely likely* to adopt an autonomous vehicle, relative to their non-university counterparts.

Comparing across generations, baby boomers and the great generation in a well-informed market segment are less *likely* or *extremely likely* to adopt an autonomous vehicle, relative to their younger counterparts (i.e., the millennials, and the Gen-X-ers). These findings are interesting to the analyst. Despite being equally aware of the potential benefits and concerns with autonomous vehicles, the older generations seem to want to adopt a wait-and-watch approach before they use emerging vehicle technologies such as autonomous vehicles in comparison to their younger cohorts. Differences across generations concerning technology adoption is a widely researched topic with interesting insights on certain generations over their counterparts (Zickuhr, 2011; Smith, 2011; Smith, 2013; Anderson, 2015). Additionally, transportation literature also points towards generational-level differences in transportation decisions and overall travel behavior (Circella et al., 2016).

Table 4-9 Marginal Effects for Significant Parameters in the Well-Informed Market Segment

Variable Description	**Marginal Effects**				
	Extremely Unlikely	**Unlikely**	**Unsure**	**Likely**	**Extremely Likely**
Male Respondent Indicator (1 if respondent is male, 0 otherwise)	-0.018	-0.050	-0.038	0.068	0.038
University Respondent Indicator (1, if respondent is a student, faculty, or staff at USF, 0 otherwise)	0.045	0.110	0.068	-0.152	-0.07
Baby Boomer Indicator (1 if respondent is classified as baby boomer, 0 otherwise)	0.023	0.061	0.040	-0.085	-0.039
Great Generation Indicator (1 if respondent is classified as belonging to the great generation, 0 otherwise)	0.057	0.127	0.067	-0.180	-0.071
White Respondent Indicator (1 if respondent is classified as white, 0 otherwise)	0.005	0.016	0.013	-0.021	-0.013
High Income Household Indicator (1 if respondent belongs to a household that earns an annual income more than $100,000, 0 otherwise) *Standard deviation of parameter*	-0.009	-0.027	-0.021	0.036	0.021
Two Person Household Indicator (1 if respondent belongs to a two person household, 0 otherwise)	0.001	0.004	0.003	-0.005	-0.003
Long Commute Time Indicator (1 if respondent travels 45 minutes or more one-way for their commute, 0 otherwise)	-0.014	-0.046	-0.040	0.059	0.041
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns zero vehicles, 0 otherwise)	-0.024	-0.088	-0.094	0.097	0.110
Recent Vehicle Purchase Indicator (1 if respondent recently purchased or leased a new vehicle, 0 otherwise)	-0.018	-0.052	-0.039	0.071	0.038

White respondents in a well-informed market segment are less *likely* or *extremely likely* to adopt autonomous vehicles when they become available in the market. The effect of this ethnicity variable varies across the population in a well-informed market segment (Table 4-9), again implying heterogeneous effects suggesting, for example, that not all white respondents in a well-informed market segment behave in the same way.

Model estimation results indicate the significance of several household-level indicators towards consumers' intended adoption (or non-adoption) of autonomous vehicles in a well-informed market segment. For instance, high-income households in a well-informed market segment are more *likely* or *extremely likely* to adopt autonomous vehicles when they become available in the market. It is likely that high-income households are also exposed to greater amounts of discussion and discourse on emerging vehicle technologies and therefore see the merit in early adoption of such technologies. However, the effect of the variable was found to vary significantly across respondents (producing a statistically significant random variable), suggesting considerable heterogeneity across all the observations.

On the other hand, respondents in a two-person household are less *likely* or *extremely likely* to adopt an autonomous vehicle when they become available in the market. This parameter also produced a statistically significant random variable suggesting that not all two-person households are same in their adoption (or non-adoption) decisions. Similar to that observed in a benefits-dominated market segment, respondents who commuted 45 minutes or more one-way, on average, for their commute are more *likely* or *extremely likely* to adopt autonomous vehicles when they become available in the market. This parameter also produced a statistically significant random variable suggesting that not all long commutes are the same. Lastly, zero-vehicle households or those that recently purchased or leased a new vehicle in a well-informed market segment are more *likely* or *extremely likely* to adopt an autonomous vehicle when they become available in the market. Most new cars are fitted with advanced safety/automation features that make driver safer, and it's perhaps an influencing factor for such respondents to invest further in technologies that could potentially reduce crashes by 90% (NHTSA, 2014). The parameter on zero-vehicle households produced a statistically significant random parameter suggesting that not all-zero vehicle households behave the same way in their adoption (or non-adoption) decisions. This is intuitive considering zero-vehicle households could also be a reflection of consequence (economic constraints et al.) rather than choice.

4.4.4.4 Intended Adoption under a Concerns-Dominated Market Segment

Model estimation results for parameters that are significant in a concerns-dominated market segment show that being male, on average, increased the probability of being extremely unlikely to adopt autonomous vehicles when they become available in the market. Part of the reason for this statistically significant male/female difference could be due to men being more risk averse concerning new vehicle technologies in concerns-based market segment. These can be substantiated by advances in recent literature showing gender differences in risk-taking in transportation-related decisions (Abay and Mannering, 2016).

In sharp contrast to that observed in the well-informed market segment, university respondents in a concerns-dominated market segment are more *likely* or *extremely likely* to adopt an autonomous vehicle when they become available in the market. Higher amounts of exposure to the discussions and discourse on the potential benefits and concerns with emerging vehicle technologies like autonomous vehicles are possibly making these respondents wait a while before investing in them (as shown in the marginal effects in Table 4-10). Comparing across generations, the great generation respondents in a concerns-dominated market segment, on average, are less *extremely unlikely* to adopt an autonomous vehicle relative to their younger counterparts.

Table 4-10 Marginal Effects for Significant Parameters in the Concerns-Dominated Market Segment

Variable Description	Marginal Effects				
	Extremely Unlikely	**Unlikely**	**Unsure**	**Likely**	**Extremely Likely**
Male Respondent Indicator (1 if respondent is male, 0 otherwise)	0.100	-0.030	-0.042	-0.020	-0.007
University Respondent Indicator (1, if respondent is a student, faculty, or staff at USF, 0 otherwise)	-0.191	0.044	0.083	0.045	0.019
Great Generation Indicator (1 if respondent is classified as belonging to the great generation, 0 otherwise)	-0.115	0.031	0.049	0.024	0.010
White Respondent Indicator (1 if respondent is classified as white, 0 otherwise)	0.108	-0.028	-0.047	-0.024	-0.01
Low Income Household Indicator (1 if respondent belongs to a household that earns an annual income less than $50,000, 0 otherwise)	0.086	-0.029	-0.036	-0.016	-0.006
Total Daily Travel Time Indicator (1 if respondent travels more than 90 minutes every day for all their trips, 0 otherwise)	0.141	-0.052	-0.057	-0.023	-0.008
Low Parking Time Indicator (1 if respondent spends 5 minutes or less in order to park their vehicle, 0 otherwise)	0.131	-0.037	-0.056	-0.027	-0.011
Recent Vehicle Purchase Indicator (1 if respondent recently purchased a used vehicle, 0 otherwise)	0.072	-0.023	-0.30	-0.014	-0.005

These results are somewhat surprising considering that these respondents, despite foreseeing the potential issues with autonomous vehicles seem more positive about their adoption. It is very likely that senior generations are currently unable to use ubiquitous modes of transportation due to their advanced age and therefore potentially see autonomous vehicles as a solution to their travel problems. On the other hand, white respondents in a concerns-dominated market segment are more *extremely unlikely* to adopt an autonomous vehicle, relative to other ethnicities. Household income seems to be a significant parameter in adoption (or non-adoption) decisions in a concerns-dominated market segment. Respondents belonging to low-income households in a concerns-dominated market segment are more *extremely unlikely* to adopt an autonomous vehicle (refer marginal effects from table 4-10), somewhat unsurprisingly.

Current travel characteristics are influential aspects in adoption (or non-adoption) decisions regarding autonomous vehicles. For instance, respondents who spent 90 minutes or more, on average, traveling daily for all their trips are more *extremely unlikely* to adopt an autonomous vehicle when they become available in the market. It is possible that spending more time on the road in an already concerns-dominated environment perhaps increases their skepticism of the effectiveness of emerging vehicle technologies to improve safety and related aspects. Lastly, the influence of parking and vehicle purchase inventories is observed on respondents' adoption (or non-adoption) of autonomous vehicle technologies. Respondents who spent 5 minutes or less parking their vehicle during their commute trip or those who recently purchased a used vehicle are more *extremely unlikely* to adopt autonomous vehicles when they become available in the market.

4.5 Summary and Conclusions

This study presents a statistical analysis of consumers' perception of benefits and concerns on autonomous vehicles with regard to the intended adoption of autonomous vehicles. In order to accomplish this, we conduct a survey of two different target groups of interest – (1) faculty, students, and staff from a large university (University of South Florida) and (2) the members of the AAA Foundation of the southeastern United States – asking them about their opinions on the potential benefits and concerns with autonomous vehicles.

A two-step cluster analysis is employed on the eleven perception variables (benefits and concerns) in order to identify autonomous vehicle consumer market segments. The identified market segments (clusters) are – (1) benefits-dominated market segment, (2) the unknown market segment, (3) the well-informed market segment, and (4) concerns-dominated market segment. A multinomial logit model was then estimated to determine the probability of a respondent belonging to a particular autonomous vehicle consumer market segment. Our estimation results show the influence of different factors such as gender, respondent characteristics, household characteristics, current travel characteristics, and crash history on the probability of respondents belonging to a particular autonomous vehicle consumer market segment.

I. Gender has a significant role on the probability of belonging to a particular market segment. Males, on average, enjoy a higher awareness of the benefits of autonomous vehicles in comparison to their female counterparts and thus have a higher probability of belonging to the benefits-dominated market segment.

II. In comparison with the golden generation, Millennials have a higher probability of belonging to the well-informed market segment while baby boomers have a higher probability of belonging to the concerns-dominated market segment than their senior counterparts.

III. Socio-economic characteristics are important indicators for understanding consumers' likelihood of belonging to a particular autonomous vehicle consumer market segment. For instance, while graduate degree holders have a lower probability of belonging to the concerns-dominated segment, high-income households have a lower probability of belonging to a concerns-dominated market segment.

IV. Current travel characteristics are significant influences in understanding consumers' probability of belonging to a particular autonomous vehicle market segment. While traveling longer distances for commute, and spending more time on a one-way commute trip increase respondent's probabilities of belonging to the benefits-dominated and the well-informed market segments respectively, it was found that non-commuters have a higher probability of belonging to the uncertain market segment.

V. Households that own more than three vehicles have a higher probability of being in the concerns-dominated market segment, likely exhibiting an entrenchment to the driving culture. On the other hand, households which recently purchased or leased new vehicles are less likely to be in the concerns-dominated market segment, and those with 3 or more licensed drivers have a lower probability of being in the uncertain market segment.

While the results from this exercise could be used to enhance our understanding of the differences among the various consumer market segments, this does not, as of yet, provide any conclusive evidence of their behavior towards intended adoption (or non-adoption) of autonomous vehicles. In order to enhance our understanding in this regard, separate ordered probit intended adoption models are estimated on each of the four previously determined consumer market segments. Our estimation results show the influence of different factors such as gender, respondent characteristics, household characteristics, current travel characteristics, and crash history on consumers' intended adoption of autonomous vehicles when they become available in the market.

I. Gender has a significant role in adoption (or non-adoption) decisions in the well-informed as well as the concerns-dominated market segments. While males, on average, are more likely to adopt autonomous vehicles in well-informed market segment, they are extremely unlikely to adopt autonomous vehicles in a concerns-dominated market segment. Gender was insignificant in the adoption decisions made by the benefits-dominated as well as the uncertain market segments.

II. Different generations behave differently when it comes to the adoption of emerging vehicle technologies such as autonomous vehicles. While generational-level influence was absent in the uncertain market segment, other model results revealed that not all millennials and baby boomers in a benefits-dominated market segment exhibited the same adoption behavior, relative to the Gen-X-ers. In contrast, the great generation is more likely to adopt autonomous vehicles in a concerns-based market segment (relative to their younger cohorts) and less likely in a benefits-based (relative to gen-X-ers) as well as the well-informed market segment (relative to the millennials and the gen-X-ers).

III. Socio-demographic characteristics are important indicators for understanding consumers' likelihood of adopting autonomous vehicles. For instance, while low-income households are less likely to adopt autonomous vehicles in uncertain as well as concerns-dominated market segments, high-income households are more likely to adopt autonomous vehicles in a benefits-dominated as well as a well-informed market segment.

IV. Several model results show the influence of current travel characteristics on consumers' likelihood of adopting (or non-adopting) autonomous vehicles. While traveling shorter distances for commute made respondents less likely to adopt autonomous vehicles in benefits-dominated as well as uncertain market segments, it is interesting to note that respondents who spent more than 90 minutes, on average, on all travel during a day are less likely to adopt autonomous vehicles in a concerns-dominated market segment.

V. Multi-vehicle households in benefits-dominated as well as uncertain market segments are less likely to adopt autonomous vehicles, likely exhibiting an entrenchment to the driving culture. On the other hand, households which recently purchased or leased a new vehicle are more likely to adopt autonomous vehicle as they are likely to be more exposed to enhanced safety and automation features with their recently purchased vehicle.

The insights obtained from this study can be used to target consumer market segments that are more likely to adopt autonomous vehicles when they become available in the market. The study can also help better understand the sentiments of the general public relating to their willingness to use such emerging technologies. However, it is important to keep in mind that people's perceptions of emerging vehicle technologies like autonomous vehicles are not likely to be temporally stable. People's perceptions of these technologies will be altered as autonomous vehicle technology becomes more and more sophisticated – with higher amounts of debate, discussion, user experience on these technologies. Thus it is important to view the findings in this paper with some caution in light of this.

CHAPTER 5: SHARED AUTONOMOUS VEHICLES AND THEIR POTENTIAL IMPACTS ON HOUSEHOLD VEHICLE OWNERSHIP

5.1 Introduction

Emerging automotive and transportation technologies, such as autonomous vehicles, have created revolutionary possibilities with regard to future travel. Several prominent automotive and technology companies have presented their versions of autonomous vehicles, and are predicting that autonomous vehicle technology, with the capability of being fully self-driving, will be available to the general public in the near future (Fagnant & Kockelman, 2015a; Menon et al., 2016). With fully self-driven vehicles, users may not need to be engaged in the driving process and could, therefore, be involved a host of other activities such as working, talking to friends, sleeping or reading (Le Vine et al., 2015).

As the technological development is progressing rapidly, governmental agencies are grappling with how to plan transportation systems for such technologies. Considering the high initial cost of owning these technologies, there is a significant discussion on the possible emergence of shared autonomous vehicle fleets as an alternative to owning individual autonomous vehicles. Shared autonomous vehicles could prove to be an inexpensive, on-demand mobility service that could play a key role in the future transportation systems. For instance, shared autonomous vehicles could provide convenient last-mile (transporting people from transit drop-offs to final destinations) solutions to support multimodal transportation systems (Krueger et al., 2016). In fact, recent literature modeling different scenarios with shared autonomous vehicle fleets show significant cost benefits in comparison to individually owned and operated vehicles (Fagnant and Kockelman, 2015a).

Past studies on understanding household vehicle ownership trends have provided interesting insights on what triggers the acquisition as well as the relinquishment of vehicles. There has been a downward trend in vehicle purchases over the last few years among younger generations (Millard-Ball & Schipper, 2011) and, over the years, the influence of life events on household vehicle relinquishments has been well documented (Dargay & Hanly, 2007; Oakil et al., 2014; Clark et al., 2015). Even without automation, there is increasing evidence that the emergence of vehicle-sharing services is leading to a reduction in household vehicle ownership (Elliott & Shaheen, 2011; Kornhauser et al., 2016). For instance, individuals who currently own vehicles out of necessity, rather than preference, are likely to switch to vehicle-sharing, if provided at a cost comparable to owning a personal vehicle. There is an increasing possibility of higher levels of vehicle relinquishment at the household level when technologies take the task of driving away from the driver.

Recent news on the emergence of popular vehicle-sharing services such as Uber (Somerville, 2016; Brewster, 2016) and Lyft (Kosoff, 2016), have supported the need to understand possible shifts in household vehicle ownership trends with the introduction of shared autonomous vehicles. While a relatively large number of previous studies have focused on understanding people's preferences for autonomous vehicles and their intended adoption (Schoettle and Sivak, 2014; Menon et al., 2016), only a few studies have explicitly dealt with the adoption of shared autonomous vehicles. Examples include Haboucha et al., (2015), who conducted a stated preference questionnaire to 800 individuals living in Israel and North America to develop a joint ownership and choice model that included shifting to a fleet of shared autonomous vehicles among other options (retain vehicle, buy and ride in an autonomous vehicle). And Bansal et al., (2016), who analyzed individuals' frequency of use of shared autonomous vehicles under different pricing scenarios and identified characteristics of potential shared autonomous vehicle users. Furthermore, studies generally do not explicitly address households' tendency to relinquish vehicles in the presence of shared autonomous vehicles. Yet, people's willingness to relinquish household vehicles in the presence of shared autonomous vehicles is a key to the success of shared autonomous vehicle systems.

Therefore, the objective of this study is to understand the factors influencing households' intentions to relinquish their own vehicles in the presence of shared autonomous vehicles. To this end, we conduct a survey of two different target groups of interest – (1) faculty, students, and staff from a large university (University of South Florida) and (2) the members of the AAA Foundation of the southeastern United States – asking how likely they would be to consider relinquishing one of their household's personal vehicles if shared autonomous vehicles were available (thus reducing their household vehicle ownership level by one). Possible responses to the question are: *extremely unlikely*, *unlikely*, *unsure*, *likely*, and *extremely likely*. For single-vehicle households, this would be relinquishing their only vehicle, and for multi-vehicle households (households owning two or more vehicles) this would be relinquishing one of their vehicles. Therefore, two different random parameters ordered probit models are estimated to analyze the factors that influence the households' likelihood of relinquishing one of their vehicles – one model for single-vehicle households and the other model for multi-vehicle households. While people's opinions of shared autonomous vehicles will likely evolve (as well as fluctuate) with the increasing penetration of new autonomous vehicle technologies and the realization of their benefits (or negative impacts), the model results provide important initial insights into the likely effects of shared autonomous vehicles on household vehicle ownership in the short term.

The remainder of our paper starts, in section 5.2, with an assessment of recent trends in vehicle acquisition and relinquishment and goes on, in Section 5.3, to a discussion of ideas relating to shared autonomous vehicles and their potential impacts on vehicle ownership. Section 5.4 describes the data used for the analysis. Section 5.5 presents the random parameters ordered probit modeling methodology used to study possible household vehicle relinquishment. Section 5.6 discusses the statistical results, and Section 5.7 discusses their implications for vehicle ownership (vehicle relinquishment, to be precise) in a shared-autonomous-vehicle environment. Section 5.8 concludes the paper.

5.2 Vehicle Ownership Trends

Since the turn of the millennium, vehicle ownership levels have seen a steady decline among the young (Millard-Ball and Schipper, 2011; Kuhnimhof et al., 2013; Metz, 2013). Recent studies have shown that this growing trend among millennials (those who are born in the 1980s and 1990s) would make them own fewer vehicles, drive less and be less likely to obtain driving licenses (Polzin et al., 2014). The reasons for this decline in vehicle purchases have been attributed to many factors including changing preferences in urban living, increased transit use, increased environmental awareness, and shifting economic circumstances (McDonald, 2015; van Wee, 2015). While several studies have pointed to the role of new technologies in reducing travel and therefore a decline in vehicle ownership levels (van Wee, 2015), others take the more skeptical view that new technologies can often create new travel demand and more travel, not less (Mokhtarian, 2002, 2009; Blumenberg et al., 2012).

Past research has shown that the relinquishment of motorized vehicles is usually the result of a life-changing event that typically leads to changes in travel behavior (Dargay and Hanly, 2007; Beige and Axhausen, 2012; Chatterjee et al., 2013; Clark et al., 2015). As an example, Oakil et al. (2014) examined households in the Netherlands and found an association between vehicle relinquishments and childbirth in households. Another study by Zhang et al. (2014) conducted in Japan shows how vehicle ownership changes were more influenced by residential moves than by changes in education or employment.

5.3 Vehicle Ownership in the Presence of Shared Autonomous Vehicles

Vehicle-sharing is considered a flexible mobility option that offers the flexibility of a private vehicle without the responsibilities associated with private vehicle ownership (Shaheen and Cohen, 2013). The potential benefits envisioned with vehicle-sharing include the facilitation of multi-modal travel behavior (Nobis, 2006) and eventually the reduction in vehicle ownership levels (Martin et al., 2010; Firnhorn and Müller, 2012).

Vehicle-sharing with autonomous vehicles has the potential to revolutionize travel with respect to the conventional vehicle- and ride-sharing paradigms. Because shared autonomous vehicles will be able to drive up to potential passengers, walking times to access shared vehicles could potentially be almost reduced to zero. Conventional vehicle-sharing has suffered from availability concerns for one-way vehicle-sharing users because there may not always be a vehicle available for use at the destination once travelers finish their activity. Thus, conventional vehicle sharing requires substantial costs to rebalance the potential mismatch of supply and demand. A shared autonomous vehicle-based vehicle-sharing model has the potential to avoid such issues (Fagnant and Kockelman, 2014; Firnhorn and Müller, 2015).

Ridesharing with a shared autonomous vehicle fleet could alleviate many of the adverse environmental impacts of current on-demand mobility services. For example, a recent simulation-based study of a shared autonomous vehicle fleet in Austin, Texas (Fagnant and Kockelman, 2015b) showed that the excess vehicle kilometers traveled due to empty vehicle relocation could be reduced by almost 50% with shared autonomous vehicle ridesharing relative to current, conventional ridesharing services. Besides, implementing ridesharing services with the use of shared autonomous vehicles would eliminate the transaction costs involved with having a driver operate the vehicle from origin to destination (Krueger et al., 2016).

While there is ample literature on the potential users of autonomous vehicles, there is substantially less information on potential user groups when it comes to shared autonomous vehicles. Past research points towards shared autonomous vehicles becoming an attractive mobility option for subgroups of the population such as the elderly or individuals who are currently unwilling and/or unable to drive (Rosenbloom, 2001; Alsnih & Hensher, 2003; Fagnant and Kockelman, 2015a). For example, research by Sikder & Pinjari (2012) found that while elderly may become immobile due to physical and cognitive limitations, their desire to continue to be mobile remains. Thus, shared autonomous vehicles could act as an elderly mobility alternative with the possibility of providing convenient and flexible mobility at a lower cost without the burden of driving. It should be pointed out, however, that it has been shown that population subgroups, such as elderly cohorts, are highly heterogeneous and vary considerably with respect to their motives for travel and the use of different modes (Haustein, 2012). In addition to the elderly, shared autonomous vehicles could be thought of as an age-appropriate mobility alternative for travelers who do not have access to private transportation, regardless of their age (Anderson et al., 2014; Krueger et al., 2016).

There is little academic literature on the impact of shared autonomous vehicles on future household vehicle ownership trends in terms of both acquisitions and relinquishments. Although, recent discussions on potential vehicle ownership impacts have been fueled by the investment of vehicle-sharing and ride-sharing companies like Uber and Lyft in the autonomous vehicle market. With regard to the impacts of the emerging shared-autonomous-vehicle business models on future vehicle ownership, Lyft predicts that vehicle ownership will all but end by 2025 (Kosoff, 2016). And, Jaynes (2016) provides a comprehensive discussion on this topic by explaining the various scenarios that may arise regarding vehicle ownership in a driverless era. For example, Jaynes argues that it is very likely that the ownership model will never change for luxury vehicle buyers. However, it seems likely that luxury vehicle brands may start offering different ownership programs to cater to a driverless world with the traditional model with full ownership, and a more flexible fractional ownership model where the people pay a price depending on their usage. Other possible models of ownership that would arise in a driverless world with shared autonomous vehicles could include an own-plus-share model where people could still be tied to the traditional vehicle ownership but be able to opt into a sharing program where their vehicles would autonomously drive and chauffeur people around during its idle time (Jaynes, 2016).

From a market-impact perspective, a number of studies have found that shared autonomous vehicles have the potential to displace conventional vehicles (Wang et al., 2006; Spieser et al., 2014; Fagnant and Kockelman, 2014), but the magnitude of this displacement has been estimated to vary widely and is not well understood. Still, individuals' willingness to relinquish their conventional household vehicles in the presence of available shared autonomous vehicles is critical to measuring the impact and success of shared autonomous vehicles.

Given the above discussions, it is clear that future household vehicle ownership decisions in the presence of shared autonomous vehicles are going to be complex, and involve individual perceptions with regard to technology, potential benefits, likely costs, and so on. The objective of the current paper is to develop some insights into these decisions by studying the willingness of people to relinquish a currently held household vehicle when shared autonomous vehicles become available.

5.4 Data

To understand the factors that may influence people's willingness to relinquish a household-owned vehicle in the presence of shared autonomous vehicles (thus reducing their household vehicle ownership level by one), a web-based survey was conducted to target population groups. The first targeted group is the students, faculty, and staff of the University of South Florida (USF) system (all three campuses – Tampa, St. Petersburg, and Sarasota-Manatee), and the second targeted group is members of American Automobile Association (AAA) South. These surveys were disseminated for data collection during April and June 2015, respectively. Both surveys collected a wide range of data relating to socioeconomics, commuting behavior, vehicle crash experience, and vehicle inventory.

Using data collected from both the target groups, a total of 1214 observations were available to study people's willingness to relinquish their household vehicles in the presence of a shared autonomous vehicles (for single-vehicle households this would be relinquishing their only vehicle, for multi-vehicle households, households owning two or more vehicles, this would be relinquishing just one of their vehicles). In our data, 27.5% of respondents indicated their likelihood of relinquishing a household vehicle in the presence of shared autonomous vehicles as extremely unlikely, 26.7% as unlikely, 19.4% as unsure, 18.6% as likely and 7.3% as extremely likely.

Table 5-1 Descriptive Statistics of the Variables of Interest in Understanding Respondent's Willingness to Relinquish a Household Vehicle with the Introduction of Shared Autonomous Vehicles for Single-Vehicle Households (Multi-Vehicle Household Values in Parentheses)

Variable Description	**Mean**	**Standard Deviation**
Male Respondent Indicator (1 if respondent is male, 0 otherwise)	0.420 (0.605)	0.494 (0.489)
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise)	0.393 (0.109)	0.489 (0.312)
White Respondent Indicator (1 if respondent is classified as white, 0 otherwise)	0.822 (0.866)	0.383 (0.341)
Post Graduate Indicator (1 if respondent's highest educational qualification is a post graduate degree, 0 otherwise)	0.372 (0.371)	0.484 (0.483)
Multi-Person Household Indicator ((1 if respondent is a member of a household with more than 3 persons, 0 otherwise)	0.086 (0.252)	0.281 (0.435)
Single Licensed Driver Household Indicator (1 if respondent is a member of a household with only one licensed driver, 0 otherwise)	0.465 (0.080)	0.499 (0.266)
Vehicle Ownership Indicator (1 if respondents is a member of a household that owns three or more vehicles, 0 otherwise)	— (0.407)	— (0.491)
Moderate Commute Distance Indicator (1 if respondent travels a one-way distance less than 10 miles for their commute, 0 otherwise)	0.348 (0.211)	0.477 (0.408)
High Daily Travel Time Indicator (1 if respondent travels more than 90 minutes every day for all their trips, 0 otherwise)	0.158 (0.156)	0.365 (0.363)
Low Parking Time Indicator (1 if respondent spends 5 minutes or less in order to park their vehicle, 0 otherwise)	0.465 (0.650)	0.499 (0.477)
Crash Indicator (1 if respondent has been involved in a traffic crash in the past, 0 otherwise)	0.688 (0.766)	0.464 (0.423)
Complete Vehicle Damage Indicator (1 if respondent was in a crash that resulted in their vehicles suffering complete damage, totalled, 0 otherwise)	0.216 (0.231)	0.412 (0.422)
No Injury Severity Indicator (1 if the respondent was involved in one or more crashes, but no respondent-involved crashes resulted in injury, 0 otherwise)	0.676 (0.640)	0.468 (0.480)

Table 5-1 provides summary statistics for some key elements of the sample. This table shows that roughly one-fifth of those surveyed were millennials (20.7%) and that 37.1% of the respondents possessed a graduate degree. Nearly one-fourth of the respondents belonged to households with an annual income below $50,000 (24.1%) and traveled a one-way commute distance of fewer than 10 miles (25.8%). However, a majority of the respondent households owned multiple vehicles (65.7%) and had been involved in a crash prior to taking the survey (74%).

5.5 Methodology

Several statistical/econometric modeling approaches are available to capture the influence of multiple factors that may affect vehicle ownership decisions in the presence of shared autonomous vehicles. In the current study, we will estimate a random-parameter ordered probit model where the dependent variable (peoples' willingness to relinquish a household vehicle, thus reducing their household vehicle ownership level by one, in the presence of shared autonomous vehicles) is modeled as ordinal data (where respondents indicate their willingness to relinquish as; *extremely unlikely*, *unlikely*, *unsure*, *likely*, *extremely likely*).

An ordered probability modeling approach is appropriate to account for the ordering of the data, and the potential unequal differences among the ordinal categories in the dependent variable (Greene, 1997; Washington et al., 2011). An ordered probability model is derived by defining an unobserved variable, z, which is used as a basis for modeling the ordinal ranking of data. This unobserved variable is specified as a linear function,

$$z_n = \boldsymbol{\beta}\mathbf{X}_n + \varepsilon_n$$

where $\mathbf{X}$ is a vector of explanatory variables determining the discrete ordering for observation n, $\boldsymbol{\beta}$ is a vector of estimable parameters, and ε is a disturbance term. Using this equation, observed ordinal data, y_n, are defined as (with 1 = *extremely unlikely*, 2 = *unlikely*, 3 = *unsure*, 4 = *likely*, and 5 = *extremely likely*),

$$\begin{aligned} y_n &= 1 \text{ if } z_n \le \mu_0 \\ &= 2 \text{ if } \mu_0 < z_n \le \mu_1 \\ &= 3 \text{ if } \mu_1 < z_n \le \mu_2 \end{aligned}$$

$$= 4 \text{ if } \mu_2 < z_n \leq \mu_3$$
$$= 5 \text{ if } z_n \geq \mu_3,$$

where μ's are estimable parameters (referred to as thresholds) that define y_n and are estimated jointly with the model parameters $\boldsymbol{\beta}$. The estimation problem then becomes one of determining the probability of the five specific ordered responses for each observation n. This is done by making an assumption on the distribution of ε_n in Equation 1. If ε_n is assumed to normally distributed across observations an ordered probit model results (alternatively, if ε_n is assumed to logistic distributed an ordered logit model results). Note that without loss of generality μ_0 can be set equal to zero requiring estimation of three thresholds, μ_1, μ_2, and μ_3.

Assuming the disturbance terms are normally distributed (Washington et al., 2011), the ordered category selection probabilities can be written as (removing subscripting n for notational convenience),

$$P(y = 1) = \Phi(-\boldsymbol{\beta}\mathbf{X})$$
$$P(y = 2) = \Phi(\mu_1 - \boldsymbol{\beta}\mathbf{X}) - \Phi(-\boldsymbol{\beta}\mathbf{X})$$
$$P(y = 3) = \Phi(\mu_2 - \boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_1 - \boldsymbol{\beta}\mathbf{X})$$
$$P(y = 4) = \Phi(\mu_3 - \boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_2 - \boldsymbol{\beta}\mathbf{X})$$
$$P(y = 5) = 1 - \Phi(\mu_{I-1} - \boldsymbol{\beta}\mathbf{X}),$$

where $\Phi(.)$ is the cumulative normal distribution.

For model interpretation, a positive value of $\boldsymbol{\beta}$ implies that an increase in $\mathbf{X}$ will increase the probability of getting the highest response (*extremely likely*) and will decrease the probability of getting the lowest response (*extremely unlikely*), but to interpret the intermediate categories (to estimate the direction of the effects of the interior categories of *unlikely*, *unsure* and *likely*) and the probability effect of the any variable in the vector $\mathbf{X}$ on each outcome category, average marginal effects are computed at the sample mean as Equation 4 below (Washington et al., 2011).

$$\frac{P(y=n)}{\partial \mathbf{X}} = \left[\phi(\mu_{n-1} - \boldsymbol{\beta}\mathbf{X}) - \phi(\mu_n - \boldsymbol{\beta}\mathbf{X})\right]\boldsymbol{\beta},$$

where $P(y = n)$ is the probability of outcome n, μ represents the thresholds, and $\phi(.)$ is the probability mass function of the standard normal distribution. The computed marginal effects quantify the effect that a one-unit change of an explanatory variable will have on outcome category *n*'s selection probability.

Finally, there is likely unobserved heterogeneity present in the data which would result in the effect of explanatory variables to vary across individual observations or groups of observations. To account for this possibility, in the transportation literature, researchers have used random parameters models, latent class (finite mixture) models, Markov switching models, or combinations of these approaches. Using a model structure that can potentially account for unobserved heterogeneity is important because constraining parameters to be fixed across observations when they actually vary across observations can lead to inconsistent, inefficient and biased parameter estimates (Mannering et al., 2016). In this paper, the possibility of parameters varying across observations is considered by estimating a random parameters formulation with,

$$\boldsymbol{\beta}_i = \boldsymbol{\beta} + \varphi_i ,$$

where $\boldsymbol{\beta}_i$ is a vector of observation parameters and φ_i is a randomly distributed term (for example, normally distributed term with mean zero and variance σ^2). Estimation of this random parameters formulation is done by simulated maximum likelihood estimation, and we will use a 500 Halton-draw sequencing approach for the simulation as is commonly done in the literature (Bhat, 2003; Anastasopoulos & Mannering, 2009).

5.6 Model Estimation Results

Peoples' willingness to relinquish one of their household's vehicles in the presence of shared autonomous vehicles is likely to be much different in a single-vehicle household than it is in a multi-vehicle household (households owning two or more vehicles). This is because, among other possible reasons, multi-vehicle households will retain at least one of their current vehicles, thus being exposed to less uncertainty about the effectiveness of shared autonomous vehicle as a transportation mode relative to conventional vehicle ownership. To test if separate statistical models should be estimated for single- and multi-vehicle households, a likelihood ratio test is conducted with the test statistic $X^2 = -2[LL(\boldsymbol{\beta}_{total}) - LL(\boldsymbol{\beta}_{single}) - LL(\boldsymbol{\beta}_{multi})]$ where the $LL(\boldsymbol{\beta}_{total})$ is the log-likelihood at convergence of the model using all respondents (both single- and multi-vehicle households), $LL(\boldsymbol{\beta}_{single})$ is the log-likelihood at convergence using only respondents from single-vehicle households, and $LL(\boldsymbol{\beta}_{multi})$ is the log-likelihood at convergence using only respondents from multi-vehicle households. This test statistic is χ^2 distributed with degrees of freedom equal to the difference in the number of parameters of both of the models. The value of X^2 is 42.44, and with 21 degrees of freedom, we are more than 99% confident that the null hypothesis that the single- and multi-vehicle household respondents are the same, can be rejected. Thus separate models are estimated for single- and multi-vehicle households.

A likelihood ratio test was also conducted to determine if there were significant differences between the University of South Florida and American Automobile Association respondents. In both single- and multi-vehicle household models we could not reject the null hypothesis that the two survey groups were the same at reasonable confidence levels. Thus we do not estimate separate models for these two survey groups.

Random parameters ordered probit model results of peoples' willingness to relinquish one of their household vehicles in the presence of shared autonomous vehicles are as presented in Table 5-2 (for respondents from single-vehicle households) and Table 5-3 (for respondents from multi-vehicle households). In Table 5-4, the average marginal effects of the individual variables are presented in order to assess the influence of specific parameters on the probabilities of the five possible outcomes (*extremely unlikely*, *unlikely*, *unsure*, *likely*, and *extremely likely*). Parameters producing statistically significant standard deviations for their assumed distribution are treated as parameters that vary across the population (with each observation having its own parameter), and the remaining parameters are treated as fixed parameters because the standard deviations are not significantly different from zero (one parameter for all observations).

Table 5-2 shows that for respondents from single-vehicle households, seven parameters (indicators for male respondent, post graduate, single licensed driver household, moderate commute distance, high daily travel time, crash, complete vehicle damage) were found to vary significantly across the population. Table 5-3 shows that for respondents from multi-vehicle households, five parameters (indicators for male respondent, moderate commute distance, high daily travel time, crash, complete vehicle damage) were found to vary significantly across the population. Again, a likelihood ratio test was used to statistically compare the random-parameters and fixed parameters ordered probit models for both single- and multi-vehicle household respondents. The likelihood ratio test statistic is calculated as $X^2 = -2[LL(\boldsymbol{\beta}_{random}) - LL(\boldsymbol{\beta}_{fixed})]$ where the $LL(\boldsymbol{\beta}_{random})$ is the log-likelihood at convergence of the random-parameter ordered probit model and the $LL(\boldsymbol{\beta}_{fixed})$ is the log-likelihood at convergence of the fixed-parameter ordered probit model. The test statistic X^2 is χ^2 distributed with degrees of freedom equal to the difference in the number of parameters of both fixed and random parameters models. For respondents from single-vehicle households, the value of X^2 is 17.97, and with 7 degrees of freedom, we are more than 98% confident that the null hypothesis that the random- and fixed-parameters ordered probit models are equal can be rejected (thus justifying the use of the random parameters formulation). For respondents from multi-vehicle households, the value of X^2 is 11.97, and with 5 degrees of freedom, we are more than 97% confident that the null hypothesis that the random- and fixed-parameters ordered probit models are equal can be rejected (thus justifying the use of the random parameters formulation).

5.7 Discussion of Estimation Findings

As shown in Tables 5-2 and 5-3, gender is a statistically significant factor in relinquishing vehicle ownership in the presence of shared autonomous vehicles in both single- and multi-vehicle households. From the marginal effects in Table 5-4, being male, on average, increases the probability of being *unlikely* or *extremely unlikely* to relinquish a household vehicle in a single-vehicle household, but decreases these probabilities in multi-vehicle households, relative to their female counterparts in the presence of shared autonomous vehicles (however, in both single- and multi-vehicle households the model estimations produced a statistically significant random parameter suggesting considerable heterogeneity across the population). Although the probability influences of the male indicator variables are small on average in both models, part of the reason for this statistically significant male/female difference could be due to men being more risk averse with respect to new vehicle technologies in single-vehicle households and less risk averse in multi-vehicle households relative to females. In fact, there is a large body of literature showing gender differences in risk-taking in transportation-related decisions (Abay and Mannering, 2016).

Comparing across generations, millennials (respondents who are less than 35 years of age) are more *likely* or *extremely likely* to relinquish a household vehicle with the introduction of shared autonomous vehicles in both single- and multi-vehicle households, relative to other age groups (as shown in the marginal effects in Table 5-4).

Table 5-2 Single-Vehicle Household Random Parameter Ordered Probit Model Estimation of Respondents' Willingness to Relinquish a Household Vehicle with the Introduction of Shared Autonomous Vehicles (Extremely Unlikely, Unlikely, Unsure, Likely, Extremely Likely), All Random Parameters are Normally Distributed

Variable Description	**Estimated Parameter**	***t* statistic**
Constant	1.435	6.50
Male Respondent Indicator (1 if respondent is male, 0 otherwise) *Standard deviation of parameter*	-0.211 (*1.627*)	-1.61 (*12.38*)
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise)	0.679	4.54
Post Graduate Indicator (1 if respondent's highest educational qualification is a post graduate degree, 0 otherwise) *Standard deviation of parameter*	0.119 (*0.821*)	0.92 (*7.43*)
Multi-Person Household Indicator (1 if respondent is a member of a household with more than 3 persons, 0 otherwise)	0.935	4.21
Single Licensed Driver Household Indicator (1 if respondent is a member of a household with only one licensed driver, 0 otherwise) *Standard deviation of parameter*	-0.258 (*1.456*)	-1.83 (*12.06*)
Moderate Commute Distance Indicator (1 if respondent travels a one-way distance less than 10 miles for their commute, 0 otherwise) *Standard deviation of parameter*	0.231 (*1.221*)	1.70 (*9.98*)
High Daily Travel Time Indicator (1 if respondent travels more than 90 minutes every day for all their trips, 0 otherwise) *Standard deviation of parameter*	-0.662 (*2.150*)	-3.44 (*9.64*)
Low Parking Time Indicator (1 if respondent spends 5 minutes or less in order to park their vehicle, 0 otherwise)	-0.592	-4.36
Crash Indicator (1 if respondent has been involved in a traffic crash in the past, 0 otherwise) *Standard deviation of parameter*	0.101 (*1.239*)	0.70 (*12.60*)
Complete Vehicle Damage Indicator (1 if respondent was in a crash that resulted in their vehicles suffering complete damage, totaled, 0 otherwise) *Standard deviation of parameter*	-0.424 (*1.121*)	-2.52 (*7.32*)
Threshold, μ_1	2.168	13.55
Threshold, μ_2	3.406	16.93
Threshold, μ_3	5.308	17.36
Number of observations	417	
Log-likelihood at convergence	-581.017	

Millennials are a significant demographic in determining the course of future technology adoption as they are the largest living generation (Fry, 2016) and are set to dominate the future discussions and discourse on adoption of new technologies. These results are also in line with recent literature that looked at generational-level differences in the adoption of new technology

(Smith, 2011; Smith, 2013; Anderson, 2015), and Millennials' willingness to use multiple modes of transportation to reach a destination and the differences in their overall travel behavior and preferences towards more equitable modes of transportation. The results also make intuitive sense considering millennial attitudes towards vehicle ownership and a sharing economy (APTA, 2013; Circella et al., 2016).

Table 5-3 Multi-Vehicle Household Random Parameter Ordered Probit Model Estimation of Respondent's Willingness to Relinquish a Household Vehicle with the Introduction of Shared Autonomous Vehicles (Extremely Unlikely, Unlikely, Unsure, Likely, Extremely Likely), All Random Parameters are Normally Distributed

Variable Description	**Estimated Parameter**	***t* statistic**
Constant	1.000	6.45
Male Respondent Indicator (1 if respondent is male, 0 otherwise) *Standard deviation of parameter*	0.119 (*0.622*)	1.49 (*11.41*)
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise)	0.593	4.33
White Respondent Indicator (1 if respondent is classified as white, 0 otherwise)	-0.346	-3.03
Post Graduate Indicator (1 if respondent's highest educational qualification is a post graduate degree, 0 otherwise)	0.305	3.76
Single Licensed Driver Household Indicator (1 if respondent is a member of a household with only one licensed driver, 0 otherwise)	-0.706	-4.47
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns more than three vehicles, 0 otherwise)	-0.289	-3.54
Moderate Commute Distance Indicator (1 if respondent travels a one-way distance less than 10 miles for their commute, 0 otherwise) *Standard deviation of parameter*	0.362 (*0.386*)	3.70 (*4.50*)
High Daily Travel Time Indicator (1 if respondent travels more than 90 minutes every day for all their trips, 0 otherwise) *Standard deviation of parameter*	0.174 (*0.926*)	1.54 (*8.26*)
Low Parking Time Indicator (1 if respondent spends 5 minutes or less in order to park their vehicle, 0 otherwise)	-0.184	-2.18
Crash Indicator (1 if respondent has been involved in a traffic crash in the past, 0 otherwise) *Standard deviation of parameter*	0.272 (*0.538*)	2.33 (*11.26*)
Complete Vehicle Damage Indicator (1 if respondent was in a crash that resulted in their vehicles suffering complete damage, totaled, 0 otherwise) *Standard deviation of parameter*	-0.165 (*0.646*	-1.52 (*7.45*)
No Injury Severity Indicator (1 if the respondent was involved in one or more crashes, but no respondent-involved crashes resulted in injury, 0 otherwise)	-0.210	-2.14
Threshold, μ_1	0.816	15.14
Threshold, μ_2	1.548	22.55
Threshold, μ_3	2.737	28.03
Number of observations	797	
Log-likelihood at convergence	-1195.938	

Marginal effects in Table 5-4 show that white respondents (1 if respondents are classified as white for ethnicity, 0 otherwise) tend to be more *unlikely* or e*xtremely unlikely* to relinquish a household vehicle in multi-vehicle households relative to other ethnicities (this indicator variable was statistically insignificant in single-vehicle households). Past literature has touched on the higher levels of accessibility to automobiles enjoyed by whites (Berube et al., 2006), and their general reluctance to engage in shared transportation modes such as carpools (McKenzie, 2015). This seems to be particularly true in multivehicle households.

In contrast, respondents with a graduate degree (1 if respondents whose highest qualification was a graduate degree, 0 otherwise), in both single- and multi-vehicle households, have higher probabilities to be *likely* or *extremely likely* to relinquish a household vehicle to utilize shared autonomous vehicles when they become available in the market relative to other educational levels (see Table 5-4). However, in single-vehicle households, the effect of the variable was found to vary significantly across respondents (producing a statistically significant random variable), suggesting considerable heterogeneity across observations, whereas this variable produced a fixed parameter in the case of multi-vehicle households. In both single- and multi-vehicle households it is likely that a higher level of education exposes respondents to greater discourse and discussion on the benefits of autonomous vehicles and shared economies.

In single-vehicle households with three or more household members, respondents, on average, were found to be less *unlikely* or *extremely unlikely* (Table 5-4) to relinquish a household vehicle (this variable was statistically insignificant in the multi-vehicle household model) relative to one- and two-person households. This would seem to support the hope that shared autonomous vehicles can substantially improve mobility among larger households that are currently restricted by owning only a single vehicle.

Table 5-4 Average Marginal Effects of the Random Parameter Ordered Probit Model Estimation of Respondent's Willingness to Relinquish a Household Vehicle with the Introduction of Shared Autonomous Vehicles for Single-Vehicle Households (Multi-Vehicle Household Values in Parentheses)

Variable Description	**Extremely Unlikely**	**Unlikely**	**Unsure**	**Likely**	**Extremely Likely**
Male Respondent Indicator (1 if respondent is male, 0 otherwise)	0.037 (-0.034)	0.020 (-0.014)	-0.048 (0.011)	-0.009 (0.029)	-0.00026 (0.008)
Millennial Indicator (1 if respondent is classified as a millennial, 0 otherwise)	-0.108 (-0.132)	-0.088 (-0.093)	0.016 (0.016)	0.036 (0.148)	0.00015 (0.061)
White Respondent Indicator (1 if respondent is classified as white, 0 otherwise)	— (0.086)	— (0.050)	— (-0.019)	— (-0.087)	— (-0.030)
Post Graduate Indicator (1 if respondent's highest educational qualification is a post graduate degree, 0 otherwise)	-0.020 (-0.082)	-0.013 (-0.039)	0.028 (0.023)	0.005 (0.076)	0.00016 (0.022)
Multi-Person Household Indicator (1 if respondent is a member of a household with more than 3 persons, 0 otherwise)	-0.096 (—)	-0.226 (—)	0.232 (—)	0.090 (—)	0.00078 (—)
Single Licensed Driver Household Indicator (1 if respondent is a member of a household with only one licensed driver, 0 otherwise)	0.045 (0.239)	0.030 (0.028)	-0.059 (-0.096)	-0.011 (-0.143)	-0.00033 (-0.028)
Vehicle Ownership Indicator (1 if respondent is a member of a household that owns three or more vehicles, 0 otherwise)	— (0.082)	— (0.033)	— (-0.027)	— (-0.070)	— (-0.019)
Moderate Commute Distance Indicator (1 if respondent travels a one-way distance less than 10 miles for their commute, 0 otherwise)	-0.038 (-0.092)	-0.031 (-0.051)	0.054 (0.022)	0.011 (0.091)	0.00035 (0.030)
High Daily Travel Time Indicator (1 if respondent travels more than 90 minutes every day for all their trips, 0 otherwise)	0.149 (-0.046)	-0.004 (-0.023)	-0.126 (0.013)	-0.019 (0.044)	-0.00044 (0.013)
Low Parking Time Indicator (1 if respondent spends 5 minutes or less in order to park their vehicle, 0 otherwise)	0.106 (0.050)	0.053 (0.023)	-0.132 (-0.015)	-0.026 (-0.046)	-0.00086 (-0.013)
Crash Indicator (1 if respondent has been involved in a traffic crash in the past, 0 otherwise)	-0.018 (-0.080)	-0.009 (-0.028)	0.023 (0.028)	0.004 (0.064)	0.00012 (0.016)
Complete Vehicle Damage Indicator (1 if respondent was in a crash that resulted in their vehicles suffering complete damage, totaled, 0 otherwise)	0.085 (0.048)	0.018 (0.018)	-0.089 (-0.016)	-0.014 (-0.040)	-0.00037 (-0.010)
No Injury Severity Indicator (1 if respondent suffered no injuries in their most severe crash, 0 otherwise)	— (0.060)	— (0.024)	— (-0.019)	— (-0.051)	— (-0.014)

Estimation results in both single- and multi-vehicle models show that households with a single licensed driver (1 if respondents belong to households with only one licensed driver, 0 otherwise) on average are more *unlikely* or *extremely unlikely* to give up a household vehicle with the availability of shared autonomous vehicle alternatives (Table 5-4). Interestingly, this variable produced a statistically significant random parameter in the single-vehicle case (suggesting considerable heterogeneity across the sample) and a fixed parameter in the multi-vehicle case. In both cases, it is likely that such households may have transportation patterns that make them less willing to rely on sharing.

For the case of multi-vehicle households, households owning three or more vehicles were found to be more *unlikely* or *extremely unlikely* to relinquish one of their vehicles (see marginal effects in Table 5-4) relative to their two-vehicle, multi-vehicle household counterparts. It appears as though respondents in households with a large number of vehicles seem to be more entrenched in the private vehicle ownership culture and thus less likely to relinquish in favor of shared autonomous vehicles. Another possible reason is that high-vehicle-ownership respondents may own may have one or more vehicles largely for enjoyment and collection purposes, which would make their relinquishment less likely.

A number of model results show the impacts of current travel characteristics on vehicle ownership decisions. For example, in both single- and multi-vehicle households, if a respondent commutes a one-way distance of fewer than 10 miles, on average, they tend to be less *unlikely* or *extremely unlikely* to give up a household vehicle (Table 5-4). The effect of this variable varies across the population in both vehicle-ownership-level models (Tables 5-2 and 5-3), again implying heterogeneous effects suggesting, for example, that not all less than 10-mile commutes are the same.

In addition to commute distance, total daily travel time was found to significantly influence vehicle-relinquishment decisions (Table 5-4), with respondents from single-vehicle households who traveled more than 90 minutes on all travel in a day being more *extremely unlikely* to relinquish a household vehicle, and respondents from multi-vehicle households who traveled more than 90 minutes on all travel in a day being less *unlikely* and *extremely unlikely* to relinquish a household vehicle (Table 5-4) . Although the effect of this variable was found to vary significantly across the respondent population in both models (as reflected by the presence of a statistically significant random parameter), the findings suggest the substantive differences in the way single- and multi-vehicle households view travel times and vehicle ownership needs.

With regard to the possible effects of parking on shared autonomous vehicle adoption, for both single- and multi-vehicle household respondents, those respondents who spent 5 minutes or less on an average to park their vehicles during their commute trips were more *unlikely* or *extremely unlikely* (Table 5-3) to relinquish a household vehicle relative to people that spend longer periods parking. This shows, as expected, that parking scarcity is likely to be a major driver in shared autonomous vehicle adoption.

Three variables relating to crash history were found to be statistically significant in the model; an indicator variable depicting respondents' involvement in a crash, an indicator variable for respondents that experienced complete vehicle damage in a crash, and an indicator for respondents that did not sustain an injury in their most severe crash. In both single- and multi-vehicle households, respondents who have been involved in a crash are, on average, more *likely* or *extremely likely* to relinquish a household vehicle with the introduction of shared autonomous vehicles (Table 5-4), although the effects of this variable are heterogeneous across the population as indicated by the significant random parameter.

Among those who were involved in one or more traffic crashes, in both single- and multi-vehicle households, respondents who suffered complete vehicle damages in one of their crashes are, on average, more *unlikely* or *extremely unlikely* to relinquish a household vehicle than those who experienced moderately severe crashes, although again the effect of this variable varies across observations. It is likely that these respondents, who have experienced extensive damage crashes, are more skeptical of emerging vehicle technologies, such as autonomous vehicles, because of safety-related concerns. At the other extreme of crash severity, respondents in multi-vehicle households, who were in one or more crashes but did not sustain injuries in any crash, were also found to be more *unlikely* or *extremely unlikely* to relinquish a household vehicle. Since these people have had crash experiences with favorable injury outcomes, they may discount the potential safety benefits of shared autonomous vehicles and thus may be more reluctant to relinquish one of their vehicles than those who experienced moderately severe crashes.

Finally, it is noteworthy that variables such as household income and others were not found to be statistically significant in the models. It appears that the variables we have included (while obviously correlated with many variables not found to be significant) are statistically the best regarding modeling people's vehicle relinquishment likelihoods in the presence of shared autonomous vehicles.

5.8 Summary and Conclusions

This paper presents an initial assessment of people's likelihood of relinquishing a household vehicle (reducing their household vehicle ownership level by one) in the presence of shared autonomous vehicles. To this end, we conduct a survey of two different target groups of interest – (1) faculty, students, and staff from a large university (University of South Florida) and (2) the members of the AAA Foundation of the southeastern United States – asking how likely they would be to consider relinquishing one of their household's personal vehicles if shared autonomous vehicles were available (thus reducing their household vehicle ownership level by one). Possible responses to the question are: *extremely unlikely*, *unlikely*, *unsure*, *likely*, and *extremely likely*. For single-vehicle households, this would be relinquishing their only vehicle, and for multi-vehicle households (households owning two or more vehicles) this would be relinquishing one of their vehicles. Therefore, two different random parameters ordered probit models are estimated to analyze the factors that influence the households' likelihood of relinquishing one of their vehicles – one model for single-vehicle households and the other model for multi-vehicle households.

Our estimation results show that for single-vehicle households, seven parameters (indicators for male respondent, post graduate, single licensed driver household, moderate commute distance, high daily travel time, crash, complete vehicle damage) were found to vary significantly across the population and for multi-vehicle households, five parameters (indicators for male respondent, moderate commute distance, high daily travel time, crash, complete vehicle damage) were found to vary significantly across the population. Different influential factors relating to gender, respondent characteristics, household characteristics, current travel characteristics and crash history are statistically significant and affect the likelihood of vehicle-relinquishment with the introduction of shared autonomous vehicles. The findings from this study provide key insights regarding vehicle-relinquishment in an era of shared autonomous vehicles including the following:

I. Gender has a significant but variable impact on people's likelihood of relinquishing a household vehicle when shared autonomous vehicles become available on the market. Males on average had lower probabilities of being *likely* or *extremely likely* to relinquish a household vehicle in single-vehicle household, but higher probabilities in these categories in multi-vehicle households, relative to their female counterparts.

II. Socio-economic characteristics are significant indicators towards people's likelihood of relinquishing a household vehicle for shared autonomous vehicles. For instance, millennials and graduate degree holders are more likely to relinquish a household vehicle when shared autonomous vehicles come into the market - possibly indicating their greater preferences towards a more sustainable lifestyle in comparison to their older counterparts.

III. Respondent commute distances and average daily travel times have a complex effect on the likelihood of relinquishing vehicles, one that varies considerably between single- and multi-vehicle households.

IV. While previous crash history usually makes respondents more likely to relinquish their vehicles to use emerging technologies like shared autonomous vehicles, a previous experience of suffering complete vehicle damage or no-injury makes people more *unlikely* to relinquish their vehicles in order to use shared autonomous vehicles (than those who experienced moderately severe damages).

V. Throughout our model estimations, there are substantial and statistically significant differences between single- and multi-vehicle household respondent opinions. This underscores the potentially large impact that the traditional human-driven-vehicle culture may have on new technology adoptions.

The insights obtained from this study can be used to target demographic groups most likely to adopt shared autonomous vehicles. The study can also help better understand the sentiments of the general public relating to their willingness to use such emerging technologies. However, it is important to keep in mind that people's perception of shared autonomous is not likely to be temporally stable. As autonomous vehicle technologies unfold, personal experiences, publicity, and information gathering will undoubtedly change people’s perceptions of shared autonomous vehicles. Thus it is important to view the findings in this paper with some caution in light of this. Yet, the marginal effects and the initial findings from this study will serve as a baseline for comparison of changes in people’s intentions as more such studies are conducted in the future.

CHAPTER 6: CONCLUSIONS AND SCOPE FOR FUTURE WORK

6.1 Summary and Conclusions

This study set out to achieve three main objectives centered on autonomous vehicles. They were (1) In order to accomplish these objectives, web-based multi-population surveys were disseminated to target population groups. The first targeted group is the students, faculty, and staff of the University of South Florida (USF) system (all three campuses – Tampa, St. Petersburg, and Sarasota-Manatee), and the second targeted group is members of American Automobile Association (AAA) South. These surveys were disseminated for data collection during April and June 2015, respectively. In addition to understanding various aspects regarding consumers' perceptions, intended adoption and anticipated travel behavioral implications with autonomous vehicles, both surveys collected a wide range of data relating to socioeconomics, commuting behavior, vehicle crash experience, and vehicle inventory.

Preliminary findings indicate consumers' willingness to adopt enhanced safety/automation features in their vehicles. While more than half (51%) of the respondents had no safety/automation features installed in their current vehicles, only 6% of the respondents seemed uninterested in adding these technologies into their next vehicular purchase. At a generational-level, fewer shares of millennials had any safety/automation features installed in their current vehicle, relative to their older counterparts. And surprisingly, fewer shares of millennials expressed interest in installing these features in their next vehicle as well.

Results revealed that roughly one-fifth of the respondents were unfamiliar with autonomous vehicles at the time of the survey. Higher shares of males seemed familiar with autonomous vehicles, relative to their female counterparts. Surprisingly, millennials seemed less familiar with autonomous vehicles than their older counterparts – which was against intuition. Survey respondents indicated three main benefits – (1) fewer traffic crashes and more roadway safety, (2) more productive (than driving) use of travel time, and (3) less stressful driving experience. Most respondents felt that less traffic congestion was least likely with the introduction of autonomous vehicles. Older respondents seemed less and less optimistic about the benefits of autonomous vehicles, which could perhaps be a psychological response to the possible perception of the loss of freedom with the emergence of new technology that assists/takes over their driving.

Respondents indicated their top three concerns as (1) system/equipment failure, (2) performance in unexpected traffic/poor weather conditions, and (3) safety of the AV occupant and other road users. Female respondents seemed more certain about their perceptions while higher shares of males seem to be on the fence about it. Results also reveal an increasing trend in respondent uncertainties over potential concerns with autonomous vehicles, with increasing age. While the biggest concerns for millennials, Gen-X-ers, and baby boomers revolve around safety-related aspects such as the prospect of system failure, the great generation seems most concerned about the loss of driving skill.

Close to 40% respondents were likely to use autonomous vehicles when they became available on the market. The survey asked questions on intended adoption at two stages – (1) before the survey respondents were provided information on potential benefits and concerns with autonomous vehicles, and (2) after the survey respondents were provided information on potential benefits and concerns with the autonomous vehicles. Doing this reduced the share of respondents who were uncertain about their adoption decisions by 6% – making them more certain about their intended adoption (or non-adoption) of autonomous vehicles. Males are more certain about their adoption (or non-adoption) decisions while the older generations expressed higher resistance towards adopting autonomous vehicles in comparison to their younger counterparts.

Results from the multi-population surveys revealed that 44% of the respondents aren't interested in investing in autonomous vehicles or using it as a service, and a further 37% would prefer to own an autonomous vehicle and prefer to use it for personal and family usage only. Results also reveal that respondents are willing to spend more time traveling in an autonomous vehicle than they currently do in human-driven vehicles. While this may also be an indication of additional vehicle miles traveled (VMT) in a world with autonomous vehicles, it is also indicative of the possibility of increased congestion with the introduction of autonomous vehicles. An interesting and somewhat thought-provoking finding was that significantly high shares of Millennials are not interested in taking trips with autonomous vehicles in comparison to their older cohorts. It seems that while older generations are less likely to adopt autonomous vehicles when they become available, they are willing to use them for undertaking their trips – possibly through shared autonomous vehicles (SAVs), or automated public transit.

Other travel behavioral aspects revealed preferences for similar sized vehicles in the future (78%) with a higher share of millennials preferring bigger-sized vehicles than they currently own, relative to their older counterparts. Similarly, when queried on future residential location shifts in a world with autonomous vehicles, a majority of the respondents (60%) indicated that they did not see the possibility of moving farther for better, more affordable housing. However, twice as many men, compared to women, feel they might move farther. And twice as many women, compared to men, are uncertain about their household relocation prospects. Similarly, higher shares of millennials are likely to move farther for better, more affordable housing in relation to their older peers, with the introduction of autonomous vehicles.

The second objective was to understand consumers' perceptions and intended adoption of autonomous vehicles. A two-step cluster analysis on consumers' perceptions of the benefits and concerns with autonomous vehicles revealed four autonomous vehicle consumer market segments – (1) the benefits-dominated market segment, (2) the unknown market segment, (3) the well-informed market segment, and (4) the concerns-dominated market segment. Econometric models were then estimated to understand the probability of a respondent belonging to a particular market segment. For instance, males had a higher probability of belonging to the benefits-dominated market segment, and Millennials had a higher probability of belonging to the well-informed market segment (relative to the great generation). While baby boomers had a higher probability of belonging to the concerns-dominated market segment, graduate degree holders, and households which most recently purchased/leased new vehicles had a lower probability of belonging to the concerns-dominated market segment.

The above results enhance our understanding of these consumer market segments. However, they do not provide insights on the factors influencing the intended adoption (or non-adoption) across these market segments. Therefore, ordered probit models of intended adoption are estimated; a separate model for each consumer market segment. The effect of gender was significant only in the well-informed and the concerns-dominated market segments. Males in the well-informed market segment are more likely to adopt AVs, while those in the concerns-dominated market segment are extremely unlikely to adopt autonomous vehicles. While generational differences were absent in the uncertain market segment, other model results revealed that not all millennials and baby boomers in a benefits-dominated market segment exhibited the same adoption behavior, relative to the Gen-X-ers. Household income is a significant indicator for adoption (or non-adoption) of autonomous vehicles. Low-income households in uncertain, and concerns-dominated market segments are less likely to adopt AVs, and high-income households in benefits-dominated as well as well-informed market segments are more likely to adopt AVs. Lastly, multi-vehicle households in benefits-dominated, as well as uncertain market segments are less likely to adopt autonomous vehicles, likely exhibiting an entrenchment to the driving culture. The insights obtained from this study can be used to target consumer market segments that are more likely to adopt autonomous vehicles when they become available in the market.

The final objective of this dissertation was to understand the potential implications of shared autonomous vehicles on current household vehicle ownership. Web-based multi-population surveys were used to study people's willingness to relinquish their household vehicle (reduce household vehicle ownership level by one) in the presence of a shared autonomous vehicle. Descriptive analysis revealed that 27.5% of respondents indicated their likelihood of relinquishing a household vehicle in the presence of shared autonomous vehicles as extremely unlikely, 26.7% as unlikely, 19.4% as unsure, 18.6% as likely and 7.3% as extremely likely. Two separate random parameters ordered probit models – one model for single-vehicle households and the other model for multi-vehicle households – are estimated to analyze the factors that influence the households' likelihood of relinquishing one of their vehicles.

Results reveal that males had lower probabilities of being *likely* or *extremely likely* to relinquish a household vehicle in single-vehicle household, but higher probabilities in these categories in multi-vehicle households, relative to females. Millennials and graduate degree holders are more likely to relinquish a household vehicle with the introduction of shared autonomous vehicle – possibly indicating their greater preferences towards a more sustainable lifestyle in comparison to their older counterparts. Finally, a previous crash history usually makes respondents more likely to relinquish their vehicles to use emerging technologies like shared autonomous vehicles.

6.2 Research Contributions

This dissertation makes three contributions, as discussed next.

First, the preliminary insights obtained from the multi-population surveys contribute to the existing body of literature on various aspects concerning autonomous vehicles – such as consumer willingness to use enhanced safety/automation features in current and future vehicles, consumer opinions on the benefits, and concerns with autonomous vehicles, consumer opinions on the intended adoption of autonomous vehicles, and other travel behavioral implications of autonomous vehicles – at a gender- as well as generational-level, thereby successfully showcasing the differences in perceptions across different population segments.

Secondly, the four consumer market segments identified through two-step cluster analysis are significant in enhancing our understanding of autonomous vehicles and their penetration into the marketplace. Apart from the conventional benefits-dominated, and concerns-dominated market segments, results also revealed the presence of the well-informed as well as the uncertain market segments based on consumers' perceptions of the benefits and concerns of autonomous vehicles. While the well-informed market segment seems to have a balanced viewpoint on both the benefits and concerns with autonomous vehicles, the uncertain market segment seems very skeptical of the prospects of such technologies. These findings add value to autonomous vehicle stakeholders, who could create specialized educational and marketing campaigns for these segments.

The last contribution of this research is in the form of initial findings on people's willingness to relinquish one of their household vehicles to use shared autonomous vehicles. While previous studies have separately investigated changes in household vehicle ownership, as well as the consumers' intended adoption of shared autonomous vehicles, this study, to the best of the author's knowledge, is the first of its kind to investigate potential implications of shared autonomous vehicles on household vehicle ownership. Consumers' perceptions of shared autonomous vehicles are likely to change in due course of time, as autonomous vehicle technology matures along with policy- and planning-level changes to accommodate them. Therefore, these results could provide an interesting baseline with which comparisons could be made about people's intentions when similar studies are conducted in the future.

6.3 Shortcomings of Current Research and Recommendations for Future Research

The findings of this study are based on the data collected by web-based multi-population surveys conducted in the year 2015 across target population groups. One of the shortcomings of the current research and similar work conducted elsewhere is the temporal and spatial variability in survey data. As autonomous vehicles are a fairly new concept, people's perceptions about these technologies are unlikely to be stable. It was revealed even during the course of the survey how providing information altered the opinions of the consumers to make them more certain about their adoption (or non-adoption) of autonomous vehicles. Media coverage on autonomous vehicles has increased manifold in the last two years. Therefore, it is foreseeable that even if the current survey was conducted in 2017, there might be differences in consumer opinions and observed trends in comparison to those observed in the year 2015. Therefore, it is important to view the findings of survey questionnaires of this study with some caution.

Secondly, the survey data was collected from two distinct populations. University respondents were chosen as members of the survey primarily as universities are often considered fertile breeding grounds for testing and adoption of new technologies. The AAA membership chosen for the survey includes a self-selected pool of respondents who have a membership with the American Automobile Association. While the combination of the two survey samples showed relative closeness to general population trends, this cannot still be a considered a fair reflection of the general population. Efforts could be made to conduct the survey representative samples of the general population to observe and understand public opinions regarding such technologies.

From a methodological standpoint, the findings from the current study would benefit with the inclusion of attitudinal variables that would extract a lot more information of interest to the analyst. Respondents' attitudes about a lot of everyday life decisions impact their transportation decisions as well. Therefore, future studies could incorporate attitudinal factors into the data collection and subsequent modeling. Additionally, the application of advanced econometric modeling approaches such as integrated choice and latent variable models (ICLV models) would likely enhance the amount of information gathered from these surveys.

As a majority of current works provide a deeper understanding of consumers' opinions about autonomous vehicles, future work in this field should be focused on enhancing our understanding of the various use-case scenarios with the introduction of autonomous vehicles. There is a need for an in-depth understanding of the intended adoption of autonomous vehicles with the use of stated-preference experiments that would provide the respondent with ample information on the technology (and the alternatives) to make a better-informed decision about their purchase decisions. Another interesting need for research is to understand travel behavioral impacts of autonomous vehicles in detail. The current study looks into the potential implications of shared autonomous vehicles on household vehicle ownership but does not delve into some of the longer term impacts such residential location shifts, and future vehicular travel – implications that could be better modeled with the application of ICLV models among other advanced techniques.

REFERENCES

AAA. (2016). Three-Quarters of Americans "Afraid" to Ride in a Self-Driving Vehicle. Retrieved from: http://newsroom.aaa.com/2016/03/three-quarters-of-americans-afraid-to-ride-in-a-self-driving-vehicle/ (January 10, 2017)

APTA, 2013. Millennials and Mobility: Understanding the Millennial Mindset, Report, 2013. Retrieved from: http://www.apta.com/resources/reportsandpublications/Documents/APTA-Millennials-and-Mobility.pdf (October 21, 2014)

Abay, K., Mannering, F. (2016). An empirical analysis of risk-taking in car driving and other aspects of life. Accident Analysis and Prevention 97, 57–68.

Abraham, H., Lee, C., Brady, S., Fitzgerald, C., Mehler, B., Reimer, B., Coughlin, J. F. (2016). Autonomous Vehicles, Trust, and Driving Alternatives: A survey of consumer preferences – White Paper. Retrieved from: http://agelab.mit.edu/files/publications/2016_6_Autonomous_Vehicles_Consumer_Preferences.pdf (January 12, 2017).

Agarwal, R., Prasad, J. (1998). The antecedents and consequents of user perceptions in information technology adoption. Decision Support Systems. 22 (1), 15-29.

AlixPartners. (2016). Three-Quarters of U.S. Drivers Say They'd Cede Wheel to Robot. Retrieved from: https://www.bloomberg.com/news/articles/2016-06-30/three-quarters-of-u-s-drivers-say-they-d-cede-wheel-to-robot (May 08, 2017)

Alsnih, R., Hensher, D. (2003). The mobility and accessibility expectations of seniors in an aging population. Transportation Research Part A 37 (10), 903–916.

Anastasopoulos, P.Ch., Mannering, F. (2009). A note on modeling vehicle accident frequencies with random-parameters count models. Accident Analysis and Prevention 41 (1), 153–159.

Anderberg, M. R. (1973). Cluster analysis for applications. Academic Press. New York, 1973.

Anderson, M. (2015). The demographics of device ownership. Retrieved from: http://www.pewinternet.org/2015/10/29/the-demographics-of-device-ownership/ (August 18, 2016)

Anderson, J., Kalra, N., Stanley, K., Sorensen, P., Samaras, C., Oluwota, O. (2014). Autonomous Vehicle Technology – A Guide for Policymakers. RAND Corporation, Santa Monica, CA.

Autotrader. (2017). Autotrader Study Finds 48 Percent of Car Buyers Prioritize In-Vehicle Technology Over Brand or Body Style. Retrieved from: http://press.autotrader.com/2017-01-10-Autotrader-Study-Finds-48-Percent-of-Car-Buyers-Prioritize-In-Vehicle-Technology-Over-Brand-or-Body-Style (May 08, 2017)

Badger, E. 2013. The many reasons millennials are shunning cars. Retrieved from: https://www.washingtonpost.com/news/wonk/wp/2014/10/14/the-many-reasons-millennials-are-shunning-cars/?utm_term=.bf6db77209db (October 21, 2014)

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

Barnard, M. (2016). Autonomous Cars Likely To Increase Congestion. Retrieved from: https://cleantechnica.com/2016/01/17/autonomous-cars-likely-increase-congestion/ (June 2, 2016).

Beige, S. and Axhausen, K. (2012). Interdependencies between turning points in life and long-term mobility decisions. Transportation 39(4), 857-872.

Berube, A., Deakin, E, Raphael, S. (2006). Socioeconomic differences in household automobile ownership rules: Implications for evaluation policy. Report. Retrieved from: http://socrates.berkeley.edu/~raphael/BerubeDeakenRaphael.pdf (August 18, 2016)

Bhat, C. (2003). Simulation estimation of mixed discrete choice models using randomized and scrambled Halton sequences. Transportation Research Part B 37 (1), 837–855.

Bhat, C., Paleti, R., Pendyala, R., Lorenzini, K., & Konduri, K. (2013). Accommodating immigration status and self-selection effects in a joint model of household auto ownership and residential location choice. Transportation Research Record: Journal of the Transportation Research Board, (2382), 142-150.

BikePGH. (2017). The Age of Autonomous Vehicles: AV Survey Results. Retrieved from http://www.bikepgh.org/resources/save/survey/ (May 08, 2017).

Bloomberg. (2016). Public Perceptions of Driverless Cars. Retrieved from https://newsroom.statefarm.com/download/271091/bloombergstatefarmsurveyreport-final.pdf (May 08, 2017).

Blumenberg, E., Taylor, B.D., Smart, M.J., Ralph, K., Wander, M., Brumbaugh, S. (2012). What's Youth Got To Do With It? Exploring the Travel Behavior of Teens and Young Adults (No. UCTC-FR-2012–2014). University of California Transportation Center, Berkeley, CA.

Boe, K. (2013). Generation X: the “forgotten generation” soon to be remembered (by millennials). Retrieved from: http://www.riversoftware.com/helpful-resources/blog/item/224-generation-x-the-forgotten-generation-soon-to-be-remembered-by-millennials (May 23, 2016)

Bonnefon, J-F., Shariff, A., Rahwan, I. (2016). The social dilemma of autonomous vehicles. Retrieved from: https://arxiv.org/ftp/arxiv/papers/1510/1510.03346.pdf (January 12, 2017)

Boston Consulting Group (2014). Revolution in the Driver's Seat: The Road to Autonomous Vehicles. Retrieved from: https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/?chapter=5 (May 2, 2015).

Brewster, S. (2016). Uber starts self-driving car pickups in Pittsburgh. Retrieved from https://techcrunch.com/2016/09/14/1386711/ (September 29, 2016)

Burns, L. D., Jordan, W. C., & Scarborough, B. A. (2013). Transforming personal mobility. The Earth Institute.

CTA. (2016). Revved Up and Ready: Most Consumers are excited about Driverless Cars and Their Many Benefits, says CTA Study. Retrieved from https://www.cta.tech/News/Press-Releases/2016/October/Revved-Up-and-Ready-Most-Consumers-are-Excited-A.aspx (March 28, 2017).

CUTR. (2013). Florida Pedestrian and Bike Safety Strategic Plan. Retrieved from: http://www.alerttodayflorida.com/resources/Florida_PBSSP_Feb2013.pdf (May 26, 2015)

Carinsurance.com (2013). Survey: Drivers ready to trust robot cars? Retrieved from: http://www.carinsurance.com/Articles/autonomous-cars-ready.aspx (August 13, 2014).

Casley, S. V., Jardim, A. S., and Quartulli, A. M. (2013). A Study of Public Acceptance of Autonomous Cars. Bachelor of Science Thesis. Worcester Polytechnic Institute, Worcester, MA, USA. Retrieved from: http://www.wpi.edu/Pubs/E-project/Available/E-project-043013-155601/unrestricted/A_Study_of_Public_Acceptance_of_Autonomous_Cars.pdf (May 3, 2015).

Chang, G., T. Lin, and J. Lindely. (1992) Understanding Suburban Commuting Characteristics: An Empirical Study in Suburban Dallas. Transportation Planning and Technology, Vol. 16, pp. 167–193.

Chatterjee, K., Sherwin, H. and Jain, J. (2013). Triggers for changes in cycling: the role of life events and modifications to the external environment. Journal of Transport Geography, 30, 183–193.

Childress, S., Nichols. B., Charlton, B., and Stefan, C. (2015). Using an Activity-Based Model to Explore Possible Impacts of Automated Vehicles. Presented at 94th Annual Meeting of the Transportation Research Board, Washington, D.C., 2015.

Chui, T., Fang, D., Chen, J., Wang, Y., Jeris, C., 2001. A robust and scalable clustering algorithm for mixed type of attributes in large database environment. In Proceedings of Seventh ACM SIGKDD International Conference on knowledge discovery and data mining, 263-268.

Circella, G., Fulton, L., Alemi, F., Berliner, R. M., Tiederman, K., Moktharian, P., Handy, S. (2016). What Affects Millennials' Mobility? Part I: Investigating the Environmental Concerns, Lifestyles, Mobility-Related Attitudes and Adoption of technology of Young Adults in California, National Center for Sustainable Transportation Report, May 2016.

Cisco (2013). Cisco Customer Experience Research Automotive Industry Global Data. Retrieved from: http://www.cisco.com/web/about/ac79/docs/ccer_report_manufacturing.pdf (August 13, 2014).

Clark, B., Chatterjee, K., Melia, S. (2015). Changes in level of household car ownership: the role of life events and spatial context. Transportation 43 (4), 565–599.

Cummings, M.L., Ryan, J. (2013) Shared Authority Concerns in Automated Driving Applications. Retrieved from: http://web.mit.edu/aeroastro/labs/halab/papers/cummingsryan_driverless2013_draft.pdf (August 13, 2014).

DTO. (2017). Aspiring Drivers Weigh Automotive Revolution. Retrieved from http://driving-tests.org/survey/2017/Aspiring-Drivers-Weigh-Automotive-Revolution-Survey.pdf (May 08, 2017).

Danise, A. (2015) Women Say No Thanks to Driverless Cars, Survey Finds; Men Say Tell Me More. Retrieved from http://www.nerdwallet.com/blog/insurance/2015/06/09/survey-consumer-fears-self-driving-cars/ (July 19, 2015)

Dargay, J., Hanly, M. (2007). Volatility of car ownership, commuting mode and time in the UK. Transportation Research Part A 41 (1), 934–948.

Daziano, R.A, Sarrias, M. & Leard, B. (2017). Are consumers willing to pay to let cars drive for them? Analyzing response to autonomous vehicles. Transportation Part C: Emerging Technologies, 78, 150-164.

Deloitte. (2017). The Race to Autonomous Driving: Winning American Consumers' Trust. Retrieved from https://dupress.deloitte.com/content/dam/dup-us-en/articles/3565_Race-to-autonomous-driving/DR20_The%20race%20to%20autonomous%20driving_reprint.pdf (May 08, 2017).

Dent, S. (2015) Google tests self-driving cars in Austin, Texas. Retrieved from http://www.engadget.com/2015/07/07/google-self-driving-tests-austin-texas/ (September 28, 2015)

Dowling, J. (2015). CarsGuide. First Self-driving Audi Due in Two Years. Retrieved from https://www.carsguide.com.au/car-news/first-self-driving-audi-due-in-two-years-32886 (Jan 12, 2017).

Edison, S. & Geissler, G. J Target Meas Anal Mark (2003) 12: 137. doi:10.1057/palgrave.jt.5740104

Elliot, M., Shaheen, S. (2011). The impact of carsharing on household vehicle ownership. Access 38 (Spring), 22–27.

Fagnant, D., Kockelman, K. (2014). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Transportation Research Part C 40, 1–13.

Fagnant, D., Kockelman, K. (2015a). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transportation Research Part A 77, 167–181.

Fagnant, D., and Kockelman, K. (2015b). Dynamic ride-sharing and optimal fleet sizing for a system of shared autonomous vehicles. In Transportation Research Board 94th Annual Meeting Compendium of Papers, paper no. 15-1962.

Fagnant, D. J., Kockelman, K. M., and Bansal, P. (2015c) Operations of a shared autonomous vehicle fleet for the Austin, Texas market. Proceedings of the 94th Annual Meeting of the Transportation Research Board (No. 15-1958) and forthcoming in Transportation Research Record.

Freemark, Y. (2015). Will Autonomous Cars Change the Role and Value of Public Transportation? The Transport Politic. Retrieved from: http://www.thetransportpolitic.com/2015/06/23/will-autonomous-cars-change-therole-and-value-of-public-transportation/ (December 07, 2016).

Firnkorn, J., Müller, M. (2012). Selling mobility instead of cars: new business strategies of automakers and the impact on private vehicle holding. Business Strategy and the Environment 21(4), 264–280.

Firnkorn, J., Müller, M. (2015). Free-floating electric carsharing-fleets in smart cities: the dawning of a post-private car era in urban environments? Environmental Science and Policy 45, 30–40.

Fry, R. (2016). Millennials overtake Baby Boomers as America's largest generation. Retrieved from: http://www.pewresearch.org/fact-tank/2016/04/25/millennials-overtake-baby-boomers/ (August 18, 2016)

Gfk. (2015). Connected Car: Creating a seamless life through the connected car. Retrieved from https://www.gfk.com/fileadmin/user_upload/dyna_content/Global/documents/Reports/GfK-Connected-Car-Preview-Report.pdf (Jan 12, 2017).

Greene, W.H. (1997). Econometric analysis (3rd edition). Upper Saddle River, New Jersey. Prentice Hall.

Guo, Y., Peeta, S., Mannering, F. (2016). Rail-truck multimodal freight collaboration: a statistical analysis of freight-shipper perspectives. Transportation Planning and Technology. 39 (5), 484-506.

Haboucha, C.J., Ishaq, R., Shiftan, Y. (2015). User preferences regarding autonomous vehicles: giving up your private car. In: IATBR 2015 – WINDSOR. Presented at the IATBR 2015, Windsor, U.K.

Haustein, S. (2012). Mobility behavior of the elderly: an attitude-based segmentation approach for a heterogeneous target group. Transportation 39(6), 1079–1103.

Heffner, R. R., K. S. Kurani, et al. (2007). "Symbolism in California's early market for hybrid electric vehicles." Transportation Research Part D -Transport and Environment 12(6): 396 -413.

Howard, D., and Dai, D. (2014). Public Perceptions on Self-driving Cars: The Case of Berkeley, California. Retrieved from: http://www.danielledai.com/academic/howard-dai-selfdrivingcars.pdf (August 13, 2014).

IBM Corp. Released 2014. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

IEEE. (2012). News release. Retrieved from: http://www.ieee.org/about/news/2012/5september_2_2012.html (September 15, 2013)

Insurance.com. (2014). Autonomous cars: Will you be a co-pilot or a passenger? Retrieved from: http://www.insurance.com/auto-insurance/claims/autonomous-cars-self-driving.html (August 13, 2014).

Intel. (2013). The Vote Is In: Citizens Support 'Smart Cities' with Driverless Cars, Public Service Drones and Surroundings that Sense Activities. Retrieved from: http://newsroom.intel.com/community/intel_newsroom/blog/2014/02/10/the-vote-is-in-citizens-support-smart-cities-with-driverless-cars-public-service-drones-and-surroundings-that-sense-activities (May 12, 2015).

J.D. Power. (2012). Vehicle owners show willingness to spend on automotive infotainment features. Retrieved from: http://www.jdpower.com/sites/default/files/2012049-uset.pdf (August 13, 2014).

J.D. Power. (2014). Vehicle Owners Willing to Pay for Smartphone Functionality, but Not Connectivity. Retrieved from: http://www.jdpower.com/press-releases/jd-power-reports-vehicle-owners-willing-pay-smartphone-functionality-not-connectivity (March 23, 2015).

J.D. Power. (2017). 2017 U.S. Tech Choice Study: Consumers Fear Technology Failures with Autonomous Vehicles. Retrieved from: http://www.jdpower.com/cars/articles/jd-power-studies/2017-us-tech-choice-study-results (May 08, 2017).

Jaynes, N. (2016). How driverless cars will change car ownership forever. Retrieved from: http://mashable.com/2016/05/30/car-ownership-autonomy-column/#ZhXSbHx_WqqW (August 29, 2016)

Kelly Blue Book. (2016). Future Autonomous Vehicle Driver Study. Retrieved from: http://mediaroom.kbb.com/download/Kelley+Blue+Book+Future+Autonomous+Vehicle+Driver+Study+-+FINAL.pdf (January 12, 2017)

Kornhauser, A. L. and et al. (2016). Fleet Management of Area-Wide Ride-Sharing: A First Look at what it would take to Serve New Jersey's Mobility Needs, 2016, ORF 467 Fall 2015 Final Report. Princeton University.

Kosoff, M. (2016). Lyft's president says car ownership will "all but end" by 2025. Retrieved from: http://www.vanityfair.com/news/2016/09/lyfts-president-says-car-ownership-will-all-but-end-by-2025 (September 22, 2016)

KPMG. (2013). Self-driving cars: Are we ready? Retrieved from: http://www.kpmg.com/US/en/IssuesAndInsights/ArticlesPublications/Documents/self-drivingcars-are-we-ready.pdf (August 13, 2014).

Kennedy, B., and Funk, C. (2016). 28% of Americans are 'strong' early adopters of technology. Retrieved from: http://www.pewresearch.org/fact-tank/2016/07/12/28-of-americans-are-strong-early-adopters-of-technology/ (January 12, 2017)

Krueger, R., Rashidi, T., and Rose, J. (2016). Preferences for shared autonomous vehicles. Transportation Research Part C 69, 343–355.

Kuhnimhof, T., Zumkeller, D., Chlond, B. (2013). Who made peak car, and how? A breakdown of trends over four decades in four countries. Transport Reviews 33(3), 325–342.

Kyriakidis, M., Happee, R., and De Winter, J. (2014) Public Opinion on Automated Driving: Results of an International Questionnaire among 5,000 Respondents. Retrieved from: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2506579 (May 12, 2015).

Labi, S. and Saeed, T. U. (2015). An exploratory discussion of the Impacts of Driverless Vehicle Operations on the Man-Made Environment. 1st International Conference on Mechanical and Transportation Engineering. Kuala Lumpur, Malaysia, 2015.

Le Vine, S., Zolfaghari, A., Polak, J. (2015). Autonomous cars: the tension between occupant experience and intersection capacity. Transportation Research Part C 52, 1–14.

Levin, M. W. and Boyles, S. D. (2015). Effects of Autonomous Vehicle Ownership on Trip, Mode, and Route Choice. Transportation Research Board. Washington, D.C, 2015.

Lin, P. (2013, October 8). The Ethics of Autonomous Cars. The Atlantic. Retrieved from http://www.theatlantic.com/technology/archive/2013/10/the-ethics-of-autonomous-cars/280360/ (July 23, 2015)

Litman, T. (2017). Autonomous vehicle implementation predictions. Victoria Transport Policy Institute. Retrieved from: http://www.vtpi.org/avip.pdf (May 3, 2017)

Lomas, N. (2017). Uber's autonomous test cars return to the road in San Francisco today. Retrieved from https://techcrunch.com/2017/03/27/ubers-autonomous-cars-return-to-the-road-in-san-francisco-today/ (May 18, 2017)

Mannering, F., Shankar, V., Bhat, C. (2016). Unobserved heterogeneity and the statistical analysis of highway accident data. Analytic Methods in Accident Research 11, 1–16.

Martin, E., Shaheen, S.A., Lidicker, J. (2010). Impact of carsharing on household vehicle holdings. Transportation Research Record, the Journal of the Transportation Research Board 2143, 150–158.

McDonald, N. C. (2015) Are Millennials Really the "Go-Nowhere" Generation? Journal of the American Planning Association. DOI 10.1080/01944363.2015.1057196

McKenzie, B. (2015). Who Drives to Work? Commuting by Automobile in the United States: 2013. Retrieved from: http://www.census.gov/hhes/commuting/files/2014/acs-32.pdf (August 18, 2016)

Mearian, L. (2013) Self-driving Cars Could Save More Than 21,700 Lives, $450B a Year. Computerworld. Retrieved from: http://www.computerworld.com/article/2486635/emerging-technology/selfdriving-cars-could-save-more-than-21-700-lives-450b-a-year.html (January 08, 2014)

Menon N., Pinjari, A.R., Zhang Y., and Zou L. (2016). Consumer perception and intended adoption of autonomous vehicle technology: Findings from a university population survey. Presented at the Transportation Research Board's 95th Annual Meeting, Washington DC, January 2016.

Metz, D. (2013). Peak car and beyond: the fourth era of travel. Transport Reviews 33(3), 255–270.

Millard-Ball, A., Schipper, L. (2011). Are we reaching peak travel? Trends in Passenger transport in eight industrialized countries. Transport Reviews 31(3), 357–378.

Mokhtarian, P. (2002). Telecommunications and travel: the case for complementarity. Journal of Industrial Ecology 6(2), 43–57.

Mokhtarian, P. (2009). If telecommunication is such a good substitute for travel, why does congestion continue to get worse? Transportation Letters 1(1), 1–17.

Moore, G. A. (2002). Crossing the chasm: Marketing and selling disruptive products to mainstream customers. New York: HarperBusiness.

Musil, S. (2015). CNET. Mercedes-Benz Unveils Connected, Self-driving Concept Car. Retrieved from http://www.cnet.com/roadshow/news/mercedes-benz-unveils-luxury-concept-selfdriving-car/ (Jan 25, 2016)

Navigant Research. (2014). Self-Driving Vehicles, Advanced Driver Assistance Systems, and Autonomous Driving Features: Global Market Analysis and Forecasts. Retrieved from: http://www.navigantresearch.com/research/autonomous-vehicles (May 12, 2015).

Nerd Wallet (2015). Women Say No Thanks to Driverless Cars, Survey Finds; Men Say Tell Me More. Retrieved from: https://www.nerdwallet.com/blog/insurance/survey-consumer-fears-self-driving-cars/ (May 12, 2016).

Ng, L., W. Barfield, and F. Mannering. (1998). Analysis of Private Drivers' Commuting and Commercial Drivers' Work-Related Travel Behavior. Transportation Research Record. Paper No. 98-0152.

NHTSA (National Highway Traffic Safety Administration) (2008) National Motor Vehicle Crash Causation Survey. U.S. Department of Transportation, Report DOT HS 811 059.

NHTSA (National Highway Traffic Safety Administration) (2014). Preliminary Statement of Policy Concerning Automated Vehicles. Washington, D.C.

Nobis, C. (2006). Carsharing as key contribution to multimodal and sustainable mobility behavior. Transportation Research Record, the Journal of the Transportation Research Board 1986, 89–97.

Oakil, A., Ettema, D., Arentze, T., Timmermans, H. (2014). Changing household car ownership level and life cycle events: an action in anticipation or an action on occurrence. Transportation 41(4), 889–904.

Pendyala R.M., and Bhat. C.R. (2014). Activity-Travel Behavior Impacts of Driverless Cars, 93rd Annual Meeting of the Transportation Research Board, Washington D.C.

Pew Research Center (2014). U.S. Views of Technology and the Future Retrieved from: http://www.pewinternet.org/2014/04/17/us-views-of-technology-and-the-future/ (August 13, 2014).

Pinjari, A., Augustin, B, Menon, N. (2013). Highway capacity impacts of autonomous vehicles: An assessment, White Paper, Tampa Hillsborough Expressway Authority.

Polzin, S., Chu, X., Godfrey, J. (2014). The impact of millennials' travel behavior on future personal vehicle travel. Energy Strategy Reviews 5, 59–65.

Pritchard J. (2014). 5 facts about Google's self-driving cars (and why 2017 is still a reality). Retrieved from: http://www.reviewjournal.com/life/technology/5-facts-about-google-s-self-driving-cars-and-why-2017-still-reality (June 19, 2015).

Rainie, L., and Perrin, A. (2016). Technology Adoption by Baby Boomers (and everybody else). Retrieved from: http://www.pewinternet.org/2016/03/22/technology-adoption-by-baby-boomers-and-everybody-else/ (January 12, 2017)

Ralph, K. (2015). Stalled on the road to adulthood? Analyzing the nature of recent travel changes for young adults in America, 1995 to 2009. University of California, Los Angeles

Rosenbloom, S. (2001). Sustainability and automobility among the elderly: an international assessment. Transportation 28(4), 375–408.

Ross, M. (2014). Bridging the Gap: Baby Boomers and Millennials Working Together for Social Change. Retrieved from: http://www.huffingtonpost.com/marc-ross/bridging-the-gap-baby-boo_b_5733494.html (January 12, 2017)

Schoettle, B., and Sivak, M. (2014). A survey of public opinion about autonomous and self-driving vehicles in the US, the UK, and Australia. University of Michigan, Technical Report No. UMTRI-2014-21. Retrieved from: http://deepblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf?sequence=1&isAllowed=y (August 13, 2014).

Seapine Software. (2014) Study finds 88% of adults would be worried about riding in a driverless car. Retrieved from: http://www.seapine.com/pr.php?id=217 (August 13, 2014).

Shaheen, Susan A, Cohen, Adam P, & Chung, Melissa S. (2009). North American Carsharing. Transportation Research Record: Journal of the Transportation Research Board, 2110(1), 35-44

Shaheen, S., Cohen, A. (2013). Carsharing and personal vehicle services: worldwide market developments and emerging trends. International Journal of Sustainable Transportation 7, 5–34.

Shankland S. (2013). Nissan pledges affordable self-driving car models by 2020**.** Retrieved from: http://www.cnet.com/news/nissan-pledges-affordable-self-driving-car-models-by-2020/ (June 19, 2015).

Shladover. S. E., Su. D. and Lu. X. Y. (2012). Impacts of Cooperative Adaptive Cruise Control on Freeway Traffic Flow. Transportation Research Record. Journal of the Transportation Research Board, 2324. pp. 63-70.

Sikder, S., Pinjari, A.R. (2012). Immobility Levels and Mobility Preferences among Elderly in the United States: Evidence from the 2009 national Household Travel Survey. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2318, 137-147.

Sjöberg, L. (1998), Worry and Risk Perception. Risk Analysis, 18: 85–93. doi:10.1111/j.1539-6924.1998.tb00918.x

Smiechowski J. (2014) Google's driverless prototype is ready to hit the road. Retrieved from: http://www.hybridcars.com/googles-driverless-prototype-is-ready-to-hit-the-road/ (June 19, 2015).

Smith, A. (2011). Trends in cell phone usage and ownership. Retrieved from: http://www.pewinternet.org/2011/04/28/trends-in-cell-phone-usage-and-ownership/ (August 18, 2016)

Smith, B.W. (2012). Managing Autonomous Transportation Demand. Retrieved from: https://cyberlaw.stanford.edu/files/publication/files/BWS-2012-ManagingAutonomousTransportationDemand.pdf (August 2, 2014).

Smith, A. (2013). Smartphone ownership 2013. Retrieved from: http://www.pewinternet.org/2013/06/05/smartphone-ownership-2013/ (August 18, 2016)

Somerville, H. (2016). Uber debuts self-driving vehicles in landmark Pittsburgh trial. Retrieved from: http://www.reuters.com/article/us-uber-autonomous-idUSKCN11K12Y (January 18, 2017)

Spieser, K., Ballantyne, K., Treleaven, K., Zhang, R., Frazzoli, E., Morton, D., and Pavone, M. (2014). Toward a systematic approach to the design and evaluation of automated mobility-on-demand systems: A case study in Singapore. In G. Meyer and S. Beiker (Eds.), Road Vehicle Automation: Lecture Notes in Mobility (pp. 229-245). Switzerland: Springer International Publishing.

State Farm. (2016). Self-driving cars: What to do with all that spare time? Retrieved from: https://newsroom.statefarm.com/state-farm-releases-autonomous-vehicles-survey-results/ (May 08, 2017)

Tan, P., M. Steinbach, and V. Kumar. (2006). Introduction to Data Mining. Boston: Pearson Addison-Wesley.

Tesla Motors. (2015). Your Autopilot Has Arrived. Retrieved from https://www.tesla.com/blog/your-autopilot-has-arrived (January 17, 2017).

Thierer, A. (2013) Technopanics, Threat Inflation, and the Danger of an Information Technology Precautionary Principle," *Minnesota Journal of Law, Science, and Technology* 14, no. 1 (2013): 312–50.

Thierer, A., and Hagemann, R. (2014) Removing Roadblocks to Intelligent Vehicles and Driverless Cars. Mercatus Working Paper. Retrieved from: http://mercatus.org/sites/default/files/Thierer-Intelligent-Vehicles.pdf (June 13, 2015)

UC Davis. (2017). The Future Car Is Driverless, Shared, and Electric – Survey released by the 3 Revolutions Policy Initiative. Retrieved from https://www.ucdavis.edu/news/future-car-driverless-shared-and-electric/ (May 08, 2017).

Underwood, S. E. (2014) Automated vehicles forecast vehicle symposium opinion survey. Presented at the Automated Vehicles Symposium 2014, San Francisco, CA. Retrieved from: https://www.michigan.gov/documents/mdot/Michigan_CV_Working_Group_October_9th_2014_475344_7.pdf. (November 11, 2014).

van Wee, B. (2015). Peak car: The first signs of a shift towards ICT-based activities replacing travel? A discussion paper. Transport Policy 42, 1–3.
Wang, F., Yang, M., Yang, R. (2006). Dynamic fleet management for cybercars. Proceedings of the IEEE Intelligent Transportation Systems Conference, Toronto, Canada

Volvo. (2016). Future of Driving: Survey Results. Retrieved from: https://www.media.volvocars.com/us/en-us/innovations/future-of-driving (May 08, 2017)

Washington, S., Karlaftis, M., Mannering, F. (2011). Statistical and econometric methods for transportation data analysis, Second edition CRC Press, Boca Raton, Florida.

Zhang, J., Yu, B., Chikaraishi, M. (2014). Interdependences between household residential and car ownership behaviour: a life history analysis. Journal of Transport Geography 34, 165–174.