Texas A&M Transportation Institute

Consumer Acceptance and Travel Behavior Impacts of Automated Vehicles

Final Report

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Executive Summary

This study provides a glimpse into the not-too-distant future by asking people in the general population how they would respond to the availability of self-driving vehicles, which might be on Texas roadways within a few years. Some elements of the technology are already available in vehicles today. Self-parking, adaptive cruise control, and automated braking are all available currently. In the near future, vehicles might take over driving completely.

Transportation planners, researchers, and policy makers have a keen interest in how the market for such vehicles will develop. The big promise is their ability to reduce traffic accidents. The optimistic view is that such vehicles could also create smoother traffic flow and unlock existing capacity on roadways, meaning less road building. This is because intelligent, self-driving vehicles may drive more safely and efficiently than human drivers. If a fleet of self-driving cars could come to people when needed, it would mean less personal car ownership and fewer parking lots. The safety and productivity gains would bring significant economic benefits, but the potential societal benefits will not be achieved unless these vehicles are accepted and used by a critical mass of drivers. Consumer demand and technological development will determine the pace and scale of market development.

The advent of self-driving vehicles could be truly transformative, but future acceptance and use are highly uncertain. Car ownership could change—people might own more or fewer vehicles. Residential spatial patterns could change—more people might live farther from or closer to downtown. The number of vehicle miles traveled (VMT) could increase or decrease, depending on how, when, and why people use self-driving vehicles. Because self-driving vehicles are not yet present in the traffic streams, with the exception of a few test vehicles, it is difficult to reliably predict future consumer demand. Any purported outcomes are just theoretical at this point. Basic questions exist:

- How likely are people to use self-driving vehicles?
- What are the factors that influence acceptance and intent to use?
- What is the appeal of self-driving vehicles for people?
- In what ways would people change their current travel behavior because of access to self-driving vehicles?
- How might self-driving vehicles on roadways impact traffic and congestion?

Thus far, answers to these questions have come largely in the form of speculative future visions with little or no empirical evidence. This study begins to build an evidence base for transportation policy making and decision making. The information derives from an online survey and qualitative interviews with Austin metropolitan area residents in May and June 2015. The findings are representative of this sample only, which was a microcosm of Austin area residents.

How Likely Are People to Use Self-Driving Vehicles?

Austin is an auto-centric metropolitan area. Personal vehicle ownership is high, with 95 percent of households owning at least one vehicle (compared to the national average of 91 percent, according to 2013 data from the U.S. Census Bureau's American Community Survey [ACS]). Public transit usage is low, with 5 percent of people commuting to work by any type of public transport, according to 2012 ACS data. While car-sharing, walking, and biking mode shares are not zero, the vast majority of people in the region use a personal vehicle (either as a driver or passenger) for their daily travel.

People are in a wait-and-see position in terms of acceptance and use of self-driving vehicles. Half are likely to use self-driving vehicles, and half are unlikely to use self-driving vehicles. People with definite views, either embracing or rejecting the technology, represented small slices of the sample. The top reason for being unlikely to use self-driving vehicles was lack of trust in the technology. While the vast majority (80 percent) had heard of self-driving vehicles prior to the survey, answers to interview questions clearly uncovered gaps in knowledge about them. As knowledge increases, acceptance and use should tilt in one direction or the other. If policy makers consider the potential societal benefits to be a policy priority, it would be valuable to educate the public to fill in knowledge gaps regarding the opportunities and challenges these vehicles offer.

What Are the Factors That Influence Acceptance and Intent to Use?

Going against conventional wisdom, neither age nor income was highly relevant in acceptance and intent to use. Psycho-social variables, such as technology adoption, privacy concerns, and perceptions of safety, were more influential. The only demographic variable associated with intent to use was having a physical condition that prohibits driving. While vehicle ownership per se was not a significant factor, currently owning a vehicle with highly automated features, such as adaptive cruise control, automated lane keeping, or automated parking systems, was significant in intent to use a self-driving vehicle.

What Is the Appeal of Self-Driving Vehicles for Consumers?

Why would people be likely to use self-driving vehicles? Perceptions are that such vehicles are safer; less stressful; productivity and mobility enablers, like using transit but better; and the wave of the future. Also, respondents expressed the belief that the vehicles would be adequately tested before being placed on the market—an important point for policy makers. Words used to describe the experience of riding in a self-driving vehicle were *carefree*, *relaxing*, and *convenient*. Only a few mentioned being nervous or having anxiety about the experience. Interestingly, likely users would find the ability to use self-driving vehicles to be a positive change in their traveling experience.

In What Ways Would People Change Their Current Travel Behavior?

In the future, people might access self-driving vehicles in two ways: by owning or by sharing. Private vehicle ownership was preferred over car sharing by a 3 to 1 margin—not surprising given Austin's auto-centric character. Perhaps as knowledge of how fleets of driverless taxis or driverless jitneys would operate grows, such views might change.

Given the fact that most people would prefer to own a self-driving vehicle, it is also no surprise that there would be almost no change in the number of vehicles owned due to a self-driving vehicle market—at least at this point in time. Most people said they would simply switch out one of their current conventional vehicles for a self-driving one. They did not envision a self-driving vehicle doing double duty within the household, driving itself to and from pick-ups and drop-offs, which could allow a household to divest itself of a vehicle.

Based on survey responses, VMT would stay about the same as well—at least in terms of local travel. Most people did not think their routines, routes, activities, or residential location would change, thereby increasing or decreasing VMT. About half thought their inter-city travel would increase in frequency. With the negatives of driving long distance (e.g., fatigue and stress) disappearing, inter-city travel in a self-driving vehicle was viewed as very desirable, which might have implications for air and any potential rail travel in the state. Congestion on highways and interstates could be impacted as well.

How Might Self-Driving Vehicles on Roadways Impact Traffic and Congestion?

The conventional view of travel is that it is a derived demand—not pursued for its own sake but only as a means of accessing desired activities in other locations; in other words, people want to do activities, and they travel in order to do so. Because automated vehicles appear to mitigate the penalty of travel by making it more enjoyable and productive, there is the likelihood that travel (VMT) will increase in the future. There is also the likelihood that travel in personal vehicles will increase, resulting in a reduction of travel by public transportation.

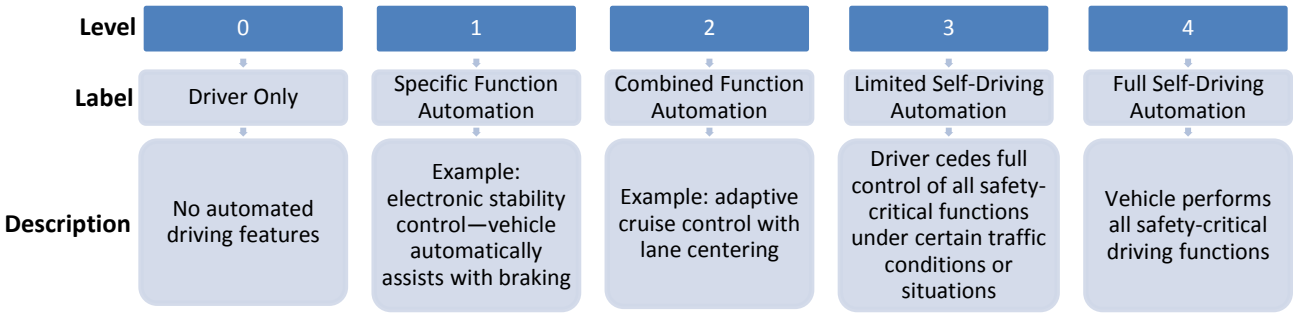
Introduction

Self-driving vehicles have the potential to bring societal benefits, such as fewer traffic accidents, reduced fuel use and emissions, less congestion, and easier parking. The question is not *if* such vehicles will be on Texas roads but *when*. It could be as soon as 2016 (*1*). Several auto manufacturers and Tier 1 suppliers have already accomplished successful precursor tests on public roads. In 2013, Mercedes' self-driving car drove 62 miles on German roads. In early 2015, a self-driving Audi A7 traveled 550 miles from San Jose, California, to Las Vegas, Nevada (*2*). In spring 2015, a self-driving car created by Delphi Automotive completed a 3,400-mile trip from San Francisco, California, to New York City, crossing 15 states (*3*). Also in summer 2015, Google began testing one of its self-driving vehicles, a retrofitted Lexus sport utility vehicle (SUV), in Austin, Texas. This testing was expanded to include its prototype pod cars in September 2015. Such road tests underscore the great leaps automated vehicle (AV) technology has taken in recent years and why insight into market demand should be important to policy makers now. Public road testing of self-driving vehicles will advance the vehicles to market, but consumer adoption and use patterns will determine the pace and scale of market development. Future adoption and use are highly uncertain.

Defining Automated Vehicles

AVs are defined as vehicles in which at least some aspects of a safety-critical control function (e.g., steering, throttle, or braking) occur without direct driver input. AVs use sensors, cameras, light detection and ranging (LIDAR), global positioning systems, and other onboard technology to operate with reduced, limited, and/or no human interaction. AVs represent a continuum of advanced driver assistance systems (ADASs), whereby more and more of the driving tasks are transferred from a driver to a vehicle for both convenience and safety. AVs can be passenger, public transport, and freight vehicles. AVs are not necessarily autonomous. Autonomous vehicles are responsible for driving solely and independently of other systems. The Google Car is an example prototype autonomous vehicle.

The National Highway Traffic Safety Administration (NHTSA) has helped to clarify policy and technical discussions around AVs by defining levels of automation (see Figure 1) (*4*). The lowest level is no automation, where the driver is in full control of steering, throttle, and braking. Vehicles with Level 2 automation, such as adaptive cruise control and lane centering, are currently in production and marketplace deployment. At Level 3, the driver is able to temporarily turn attention away from the driving task to engage in other activities but needs to be available to retake control within a few seconds' notice. At Level 4, automated systems replace the driver completely.



Source: (*4*)

Figure 1. Levels of Vehicle Automation.

An ADAS approach lends itself to evolutionary and iterative progression toward self-driving vehicles. The evolutionary approach is easier for policy making and transportation agency decision making. From a business standpoint, an incremental approach allows automakers to incorporate new features into their vehicles without major disruptions to day-to-day operations. An incremental approach also enables automakers to offer premium technology and safety-oriented car features that do not depend on breakthroughs in technology, regulation, or liability.

In this context, Google's entry into the AV space is disruptive (i.e., Google's approach is different from the approach of conventional automakers). Google's approach is to focus solely on producing a fully self-driving vehicle, thus allowing it to become a leapfrog competitor to the traditional automakers—with significant implications for state and local policy making. The two approaches are often referred to as bottom-up (i.e., incremental) and top-down (i.e., disruptive) (*5*). The top-down approach will likely result in technology developing faster than policy. Vehicles could be put on the roads prior to the necessary regulatory and policy infrastructure—much like Uber taxis operate in some jurisdictions. Regardless of whether we see bottom-up or top-down market entry, consumer demand will determine how the market for these vehicles develops.

Study Objectives

Self-driving vehicles could potentially alter travel demand and the transportation system. Will driverless taxis serve many of the trips currently made by privately owned vehicles, reducing vehicle ownership needs? Will more people bike because self-driving vehicles require narrower lanes than conventional vehicles and improved bike lanes can be accommodated? Will the elderly or people with disabilities use self-driving vehicles, thus generating added VMT and perhaps exacerbating congestion?

Because highly automated vehicles are not yet present in the traffic streams, with the exception of a few test vehicles, it is difficult to reliably predict future consumer demand. There might be various responses to the introduction of such vehicles into the market, and so basic questions exist:

- How likely are people to use self-driving vehicles?
- What are the factors that influence acceptance and intent to use?
- What is the appeal of self-driving vehicles for people?
- In what ways would people change their current travel behavior because of access to self-driving vehicles?
- What does this mean for traffic and congestion in the future?

As long as these critical questions go unanswered, states and localities will be hampered in their ability to prepare for the implications of self-driving vehicles. Thus far, answers to these questions have come largely in the form of speculative future visions with little or no empirical evidence. More recently, research has begun trying to answer these questions by collecting data and developing models.

The objective of this study was to gather empirical evidence on consumer acceptance and adoption: the factors associated with intention to use, how that intention might influence mode choice and vehicle ownership decisions, and what all of this could mean for travel demand and congestion in the Austin region. The data were gathered through a two-step process:

1. An initial online survey of 556 residents of the Austin metropolitan area.
2. Follow-up, face-to-face interviews with 44 participants.

Given that automation is a new technology, not yet on the market, extreme care was used to design the study language and content. In addition to the questionnaire, the study included a video to portray the self-driving technology in the online survey. The face-to-face interviews were used to gather information on potential travel behavior changes. The qualitative probing on such changes was deemed more reliable than survey data collection. More information about the research methodology and a description of the survey sample can be found in Appendix A.

The insights derived from this study will provide a first step in understanding how self-driving vehicles could affect Texans' travel. This information begins to build an evidence base for policy makers and transportation agencies regarding future mobility requirements and congestion mitigation needs and, therefore, future infrastructure investment.

Intent to Use Self-Driving Vehicles

In the case of self-driving vehicles, potential societal benefits (e.g., enhanced safety, reduced congestion, and improved air quality) will not be achieved unless these vehicles are accepted and used by a critical mass of drivers. Acceptance has been defined as the "degree to which an individual incorporates the system in his/her driving, or, if the system is not available, intends to use it" (*6*). With self-driving vehicles, the intent to use is an important concept because the technology is not yet on the market. When a product becomes tangible and drivers have an opportunity to experience it "for real," they can form judgments and provide reliable responses to questions pertaining to *actual* use. For this reason, this study examined intent to use rather than stated future use.

The data on intent to use self-driving vehicles and its associated factors derive from an online survey of 556 Austin residents. The survey questionnaire contained the following definition of self-driving vehicles:

> In our study, we are interested in your opinions about self-driving vehicles. You may be able to buy a self-driving vehicle from major manufacturers or access one through a car-sharing service within the next 5–8 years. A self-driving vehicle is a vehicle that controls all driving functions for an entire trip, including steering, braking, and acceleration. It covers freeway driving, neighborhood driving, and activities like parking. The operator provides destination or navigation input and is in the vehicle to take over control of the vehicle if conditions warrant. The market push for self-driving vehicles is to make driving safer and more efficient.

In addition, a link to a short video on self-driving vehicles was provided after the definition, as noted in Appendix A.

Intent to Use Segmentation

Austin residents were asked about their intent to use self-driving vehicles: "Imagine that self-driving vehicles were on the market now either for purchase or rental. What is the likelihood that you would ride in a self-driving vehicle for everyday use?" In responding, the sample was evenly split—with 50 percent indicating an intent to use and 50 percent indicating an intent not to use.

Responses to the question were used to segment respondents into four intent-to-use categories (see Figure 2). The smallest segments were those at the intense ends of the spectrum: extremely likely to use (14 percent) and extremely *unlikely* to use (18 percent). The rest of the people surveyed are in a wait-and-see mode, with most somewhat likely to use (36 percent). Only 32 percent were somewhat *unlikely* to use.

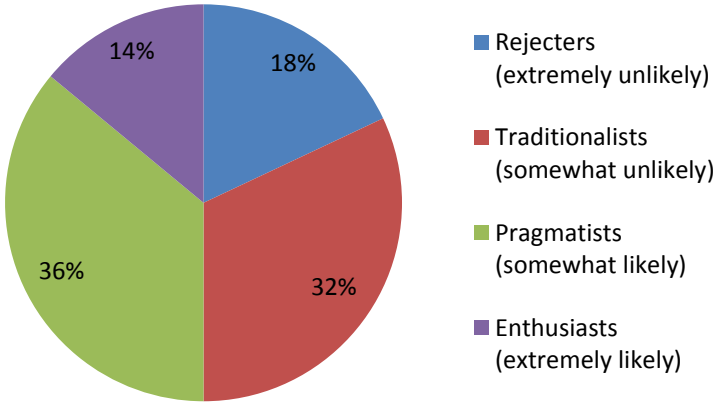


Figure 2. Intent to Use Self-Driving Vehicles (N=556).

The research team elicited rationales for intent to use through probing in the follow-up face-to-face interviews, which are discussed in detail in the section "Impact on Travel Behavior." Seven main categories of reasons surfaced in the interviews:

1. Safer than human drivers.
2. Relieves stress of driving.
3. Mobility enabler for aging seniors.
4. Ability to be productive while traveling in a car.
5. Trust that technology will be adequately tested.
6. Comparability to public transit experience.
7. Attraction of new technology.

Austin is a technology hub, and the intent to use self-driving vehicles might be influenced by its technology focus, although this is not necessarily the case for the current sample. A majority of the sample (66 percent) considered themselves Late Adopters on the technology adoption curve. They wait awhile before adopting new technology and so are not necessarily eager to jump on the self-driving car bandwagon. Early Adopters (e.g., among the first to adopt new technology) comprised 21 percent of the sample, and Laggards (e.g., among the very last) were 13 percent of the sample. Still, technology use among the survey sample was quite strong, which is reflective of Austin's character (Table 1).

Table 1. Frequency of Technology Use (N=556).

Frequency	Smartphone	Facebook	Internet Shopping	Emailing	Text Messaging	Transportation Apps
Never	10%	23%	5%	1%	7%	31%
Several times/month	3%	10%	58%	5%	7%	32%
Several times/week	5%	20%	28%	15%	20%	26%
Several times/day	41%	38%	7%	54%	45%	6%
Several times/hour	41%	9%	2%	25%	21%	5%
Total	100%	100%	100%	100%	100%	100%

Factors Associated with Intent to Use

Demographic variables were not strongly related to intent to use. For example, a respondent's age was not as predictive of his or her intent to use as one might expect. Table 2 provides the distribution of intent to use self-driving vehicles by age. Younger people (less than 30 years old) were evenly split on intent to use, as were people greater than 65 years old. A slight majority of people 30–45 years old (53 percent) were likely to use, whereas a slight majority of persons 46-65 years old (55%) were unlikely to use.

Table 2. Intent to Use Self-Driving Vehicles by Age.

Segment	Less than 30 Years Old (n=132)	30–45 Years Old (n=155)	46–65 Years Old (n=167)	65+ Years Old (n=102)
Rejecters (extremely unlikely)	24%	14%	22%	15%
Traditionalists (somewhat unlikely)	26%	33%	33%	35%
Pragmatists (somewhat likely)	39%	36%	32%	36%
Enthusiasts (extremely likely)	11%	17%	13%	14%
Total	100%	100%	100%	100%

On the other hand, having a physical condition that prevented driving was predictive. All of the small number of people (n=11) with a travel-restrictive disability were likely to use.

Gender differences were observed. Males, more than females, are likely to use, and 18 percent of males were Enthusiasts, compared to 11 percent of females. In terms of household income, most

of those with a household income less than $25,000 were unlikely to use (56 percent), while those earning $25,000–$50,000 were more likely to use (54 percent). In other income categories, people were equally unlikely and likely to use. Educational attainment was not associated with intent to use. However, the presence of children in the household was associated. Households with children were less likely to indicate intent to use than households without children (51 percent and 45 percent, respectively). However, over one-third of the 20 households in the sample with three or more children were Enthusiasts.

Half of respondents were unlikely to use. The most frequent reasons cited for being unlikely to ride in self-driving vehicles for everyday use were:

- Lack of trust in the technology (41 percent).
- Safety (24 percent).
- Cost (22 percent).

These big-picture reasons overshadowed other, more individualistic personality traits, such as liking to drive or desire for vehicle control (see Table 3).

Table 3. Reasons for Not Intending to Use Self-Driving Vehicles.

Reason	Frequency	Percent	Cumulative Percent
Lack of trust in this technology	117	41%	41%
Safety concerns	69	24%	65%
Cost concerns	61	22%	87%
Like to drive	20	7%	94%
Desire for control of vehicle	6	2%	96%
Insurance/liability uncertainties	2	1%	97%
Anti-technology in general	2	1%	98%
Lack of information about it	2	1%	99%
No need for it	2	1%	100%
	282	100%	

Data privacy was mentioned by only one individual as a reason for being unlikely to ride in a self-driving vehicle, but based on other questions, data privacy was found to be associated with intent to use self-driving vehicles (Table 4). The higher the level of data privacy concerns, the less likely a person was to use self-driving vehicles. Among total respondents, opinions on data privacy were split:

- **Few privacy concerns:** Of the total respondents, 49 percent had concerns about using Internet or Internet-enabled technologies in *some* situations or *not at all*. Of those who expressed concerns in *some* situations, 57 percent were likely to use self-driving vehicles. Of those who expressed *no* data privacy concerns, 71 percent were likely to use self-driving vehicles. Only 5 percent of the total sample indicated that they had no concerns at all.

- **Many privacy concerns:** Of the total respondents, 51 percent had concerns about using Internet or Internet-enabled technologies in *most* or *all* situations. Of those who expressed concerns in *most* situations, 57 percent were *unlikely* to use self-driving vehicles. Of those who expressed concerns in *all* situations, 60 percent were *unlikely* to use self-driving vehicles.

Table 4. Intent to Use Self-Driving Vehicles by Level of Data Privacy Concern.

Segment	Not at All Concerned (n=28)	Concerned in Some Situations (n=245)	Concerned in Most Situations (n=208)	Concerned in All Situations (n=75)
Rejecters (extremely unlikely)	11%	14%	23%	24%
Traditionalists (somewhat unlikely)	18%	30%	34%	36%
Pragmatists (somewhat likely)	43%	40%	33%	29%
Enthusiasts (extremely likely)	28%	16%	10%	11%
Total	100%	100%	100%	100%

Early Adopters of technology (in general) embraced using self-driving vehicles (Table 5). Early Adopters are among the first to adopt new technology, while Late Adopters wait awhile. Laggards are among the last to adopt new technology if at all. Age was related to the adoption curve, with the largest proportion of Early Adopters in the less-than-30 age group and the largest proportion of Laggards in the over-65 age group. Early Adopters skewed heavily toward intent to use (65 percent), whereas Laggards skewed toward not using (62 percent). The few Early Adopters who were Rejecters mainly cited concerns about cost as their main reason for not using. The small number of Laggards who were Enthusiasts tended to be either younger than 30 or older than 65.

Table 5. Intent to Use Self-Driving Vehicles by Adoption Curve.

Segment	Early Adopter (n=118)	Late Adopter (n=365)	Laggard (n=73)
Rejecters (extremely unlikely)	9%	19%	30%
Traditionalists (somewhat unlikely)	26%	34%	32%
Pragmatists (somewhat likely)	43%	37%	19%
Enthusiasts (extremely likely)	22%	10%	19%
Total	100%	100%	100%

Currently owning or leasing a vehicle had no effect on people's intent to use. However, currently owning a vehicle with highly automated features did have an effect, and these individuals were more likely to be Enthusiasts (20 percent) than those who did not own a vehicle with highly automated features (12 percent).

Among those currently employed, their commute mode was related to intent to use (Table 6). Commute mode was defined as how people usually got to work last week (i.e., the single mode used for the longest time), and 85 percent of full- or part-time workers indicated they were vehicle drivers. By a slight majority (52 percent), vehicle drivers were *unlikely* to use self-driving vehicles, whereas the majority of users of all other modes (i.e., vehicle passengers, walkers, or telecommuters) were likely to use self-driving vehicles (57 percent). This was particularly true of vehicle passengers, though they were a very small sample (n=17). The utility of self-driving cars for users of other modes, relative to drivers, might be perceived as providing greater convenience of access and egress or enhanced mobility for those who do not own a car or cannot drive.

Table 6. Intent to Use Self-Driving Vehicles by Commute Mode.

Segment	Vehicle Driver (n=304)	All Other Modes (n=53)
Rejecters (extremely unlikely)	20%	15%
Traditionalists (somewhat unlikely)	32%	28%
Pragmatists (somewhat likely)	36%	42%
Enthusiasts (extremely likely)	12%	15%
Total	100%	100%

Self-reported VMT in 2014 had no correlation with intent to use, but frequency of driving did make a difference. People who drove quite infrequently or almost never expressed a strong intention to use self-driving vehicles (Table 7). These people tended to have a travel-restrictive disability or to be low income (i.e., earning less than $24,999 in 2014), highlighting the accessibility benefits that have been tied to self-driving vehicles.

Table 7. Intent to Use Self-Driving Vehicles by Frequency of Driving a Motor Vehicle

Segment	Every Day (n=409)	A Few Days per Week (n=112)	A Few Days per Month or Almost Never (n=35)
Rejecters (extremely unlikely)	19%	20%	8%
Traditionalists (somewhat unlikely)	32%	37%	20%
Pragmatists (somewhat likely)	36%	31%	49%
Enthusiasts (extremely likely)	13%	12%	23%
Total	100%	100%	100%

Predictors of Intent to Use

There are transportation decision makers, policy makers, and even researchers with preconceptions about the types of consumers who will adopt and use self-driving vehicles. Many researchers and policy makers feel that it will be Millennials because of their reliance on technology. Others think it will be seniors because the technology will enable mobility well into old age. As the survey results indicate, demographic variables such as age might not be the best predictors of intent to use.

The prior studies discussed in Appendix B present the Car Technology Acceptance Model (CTAM), which the research team used to identify variables that explain new technology adoption and use. These variables are psychological and personality variables that distinguish users who accept or reject technologies. They include such items as attitudes toward using technology, perceived safety while driving, anxiety in the car context, and social influence. In previous technology studies, these psychological or personality variables held more predictive power than demographic variables. In other words, personal beliefs and preferences are often better predictors of technological adoption than basic demographic descriptors like age or gender. The research team conducted higher-level analyses to examine the significance of the different types of variables (e.g., demographic, personality, and behavioral) in the survey. After isolating the significant variables, a regression model was developed to examine determinants of intent to use. The results indicate that individuals who have a higher level of intent to use self-driving vehicles are the ones who:

- Have any physical conditions that prohibit them from driving.
- Think self-driving vehicles would decrease crash risks.
- Use smartphones, text messaging, Facebook, and transportation apps.
- Are not concerned with data privacy when using online technology.
- Think using a self-driving vehicle would be fun.

- Think it would be easy to become skillful at using self-driving vehicles.
- Believe people whose opinions they value would like using self-driving vehicles.

At this early stage in market development for self-driving vehicles, the personality and psychology of the consumers are much more important than their demographic profile.

Impact on Travel Behavior

Self-driving vehicles promise to make automobile travel safer and more efficient, and to dramatically change transportation planning and engineering. This is because they offer the potential to free drivers' attention from the road, to chauffer people who are unable to drive, and ultimately to drive robotically without anyone on board. But how will people's travel behavior change, if at all, because of these opportunities?

Travel behavior in this study is defined with four key variables:

- The number of vehicles owned.
- The propensity to use shared vehicles versus owning personal vehicles.
- Choices about mode of travel (e.g., vehicle driver, public transit, and walking).
- The amount of VMT.

Information about travel behavior impacts—when projected into the future—provides insight into implications for traffic generation, highway capacity, and congestion over time as self-driving vehicles comprise a greater percentage of the vehicles on the road.

The data on impacts on travel behavior originate from qualitative, face-to-face interviews with 44 people who indicated in the online survey that they would likely use self-driving vehicles and who also agreed to participate in a follow-up interview. The use of qualitative interviews, rather than a survey, enabled the researchers to ask clarifying questions to ensure accurate information was collected. This method also facilitated the capture of opinions, perceptions, and behaviors in people's own words. Characteristics of these 44 people include:

- 9 percent were less than 30 years old, 50 percent were between 30 and 45 years old, 23 percent were between 46 and 65 years old, and 18 percent were 66 years old or older.
- Most (75 percent) prefer to be the driver rather than passenger when traveling in a conventional car in an urban area, but a slight majority (55 percent) prefer to be the passenger for long-distance trips.
- The majority (71 percent) are not at all or only somewhat concerned that their data are not kept private when using Internet-enabled technologies. More (82 percent) are not at all or only somewhat concerned that their data would *not* be kept private when using self-driving cars.
- Most (69 percent) feel moderately or extremely safe in vehicles today when driving.
- Virtually all would feel safer (46 percent) or about the same as now (48 percent) in a self-driving vehicle.

Rationale for Intent to Use

It is important to find out why individuals decide to use self-driving vehicles because intention to use could provide insights into the potential impacts on travel behavior. The first question these individuals were asked was: "You indicated in the prior online survey that you would likely ride

in a self-driving vehicle for everyday use. Can you tell me your reasons for that answer?" Seven main categories of reasons surfaced in the interviews:

1. Safer than human drivers.
2. Relieves stress of driving.
3. Trust that technology will be adequately tested.
4. Comparability to public transit experience.
5. Attraction of new technology.
6. Mobility enabler for aging seniors.
7. Ability to be productive while traveling in a car.

The first five reasons (safety, relief from stress, trust, like public transit, new) spanned different age groups. For example, regardless of age, respondents felt AVs would be better drivers than humans (see Table 8).

Table 8. Reasons for Intent to Use.

Reason	Some Direct Quotes from Respondents
Safer than human drivers	If everybody is in an automated car, it would be safer (less than 30 years old). I feel as more and more people obtain such vehicles, it will increase safety and decrease human errors (30–45 years old). I get nervous driving; other drivers tend to drive carelessly. [I] would like this idea (46–65 years old). [I like the] ability to avoid other cars and traffic (65+ years old).
Relieves stress of driving	With Austin traffic, it would be convenient not to have to worry about the drive to work (45–65 years old). Mostly for lack of stress caused when driving to and from work; traffic-related [concerns] and having to pay attention (30–45 years old). [Driving] is something you have to do to get from point A to point B…if there was technology to do it, I would definitely be willing not to have to drive (less than 30 years old). I do not like to drive, especially in Austin (45–65 years old).
Comparability to public transit experience	I used public transit often when I lived overseas, and I enjoyed the ride with no responsibilities (less than 30 years old). I look at it like when I could take mass transit; I did not have to focus on driving (30–45 years old). I would be interested in using it somewhat the way you would use public transportation…read something (46–65 years old).
Trust that technology will be adequately tested	By the time they allow it on the road, it will be safer than my driving (65+ years old). Before something like this comes to market, it would be tested a lot (30–45 years old). By the time it gets to market, it will be so mistake proof, it would be safer, without human errors (46–65 years old).
Attraction of new technology	[The] first reason at this point is it is something very new and different. I like technology (46–65 years old). I already have a car that has steering assist. It reads the stop signs and signals (65+ years old). New technology, and I want to be a part of it (45–65 years old).

	It is the wave of the future (30–45 years old).

Also regardless of age, respondents thought traveling would be less stressful in self-driving vehicles, especially in Austin traffic, which they pointed out as being currently bad. In addition, several respondents described the activity of driving as "a chore." Some people equated the experience of using a self-driving vehicle to using public transit. The implication was that a self-driving vehicle would be more convenient than traditional public transit and, therefore, desirable. One thing that might have made these respondents more comfortable about using self-driving technology was their trust that the vehicles would not be allowed on the roads until proven safe. One major rationale category had to do with the attraction of new technology. Several respondents said they would likely ride in a self-driving vehicle simply because it was new.

There were also age-specific rationales, such as facilitating mobility as one grows older (see Table 9). Those individuals older than 65 years recognized that, as they were aging, such vehicles would be useful. Even a couple of the people aged 46–65 pointed out the benefits as they age. The ability to be more productive while traveling in a car was also a frequently cited rationale, especially among people between the ages of 30 and 45 years.

Table 9. Age-Specific Reasons for Intent to Use.

Reason	Some Direct Quotes from Respondents
Mobility enabler for aging seniors	By the time they allow it on the road, it will be safer than my driving. As I get older, I would find this technology more and more appealing. [Riding in a self-driving vehicle would be] easier as I get older. I get distracted, and my reflexes are not as good as they used to be. Becoming disabled soon, I will not be able to drive myself. Also entering my older years, it will benefit me.
Ability to be productive while traveling in a car	I could do something productive on my trip. We waste a lot of time behind the wheel. To be able to be productive like on a plane or rail. It would let me do other tasks, such as eating, watch a movie, be on a cell phone while you are on your trip. It would be easier to conduct business or for personal time. I spend a lot of time driving; it would nice to be able to do other things. My commute is short, but it would allow me to do other things [It would] reduce the stress of living in a big city. Get in a vehicle and work on other things. Make it a more productive trip.

Perceptions of the Self-Driving Experience

Respondents were asked to do the following: "Imagine that you are riding by yourself in a self-driving vehicle on a trip to the grocery store. Describe what you think the experience would be like." Words the respondents used to describe the self-driving experience included *nervous*, *carefree*, *convenient*, *relaxing*, and *independent*.

Several respondents said that they would be nervous at first because it is something new. They described themselves as being hyperaware of how the car is reacting and trying to figure out how

it knew to do certain things: “What is the car going to do in X situation?” Others mentioned that they might not be able to relax at first. They would feel a need to “over-correct or override the system.” Some also said:

- “I would probably have my hands on the steering wheel (if there was one).”
- “Once I knew [the car was able to handle all situations,] I would probably do other things.”

Respondents that were apprehensive were a minority. The majority of respondents ticked off the things that they would be doing on the trip such as reviewing a grocery list, using a cell phone, flipping through radio stations, taking care of personal matters, talking to children in the car, or doing work or homework. Others talked about doing nothing:

- “Get in the car and tell it where to go. It takes me there.”
- “I could relax; my mind would be free.”

When asked “Where would you sit?” most people answered the driver’s seat—at least at first. They said:

- “Driver’s seat; habits die hard.”
- “Driver’s seat in case I would have to switch it to manual.”
- “Driver’s seat. I would want to still see the controls.”
- “Still sit in the driver’s seat at least at first. Just because I am used to sitting in the driver’s seat.”

After getting comfortable with the self-driving vehicle, they would then sit in the passenger seat or the back seat, whichever would be more comfortable.

A few said that they would sit on the passenger side immediately:

- “Passenger side and probably focus on my computer surfing the web.”
- “Passenger side because there is more room and focus on whatever task I had at hand and wanted to get done.”

Potential Concerns with Using Self-Driving Vehicles

Respondents were asked, “Can you think of any potential problems or concerns you might have in using a self-driving vehicle?” The most frequently cited concerns related to system failure or malfunctions in the technology:

- “Failure of the car…is there sufficient redundancy?”
- “If you’re in a car that is connected, what happens when you lose connection?”
- “What if you get struck by lightning?”
- “You’d want to know that the car wouldn’t glitch out—leave you stranded.”
- “What if it malfunctions and causes an accident?”
- “With new technology, when it first comes out, generally there are bugs.”

Other items mentioned by a few people included "someone hacking in," "an environment where not everyone is driving a self-driving vehicle," and the "vehicle's handling of unforeseen events." The concerns about hacking were not just about hacking when the vehicle was operating, but respondents also worried about identity theft: "How does the vehicle know it is me getting into the car and not someone trying to steal my vehicle?" Cost was only mentioned by two people. Two people also mentioned losing the capability or the fun of driving.

Even though nearly 8 out of 10 survey respondents had heard of self-driving vehicles before participating in this study, most of the issues raised were actually questions about technology:

- How fast can it stop if a kid steps in front? Is the reaction time faster than a human's?
- How do I program it? Do I have to use MapQuest?
- Does it see potholes and speed bumps?
- Does it only go the exact speed limit?
- Does it know what to do at a flooding location? Does it even know that an area has the potential for flooding?
- Do I need to give it specific commands?
- Would they be rentals?
- Is it voice activated?

Interest in Owning Self-Driving Vehicles

There is much uncertainty surrounding the question of whether the self-driving vehicle market will develop as a privately owned vehicle market or a shared-vehicle market. Respondents were asked to assume that self-driving vehicles were available for use today, and were asked, "Would you be more interested in owning one or just using one, like a Car2go or Uber taxi?"

Most (59 percent) indicated they would be more interested in owning a self-driving vehicle than in using one, like a Car2Go or Uber taxi (see Figure 3).

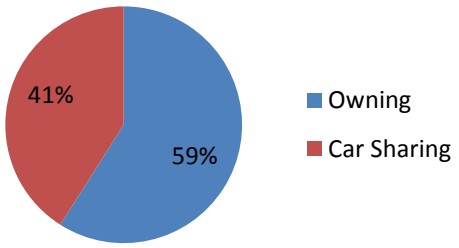


Figure 3. Intent to Use Self-Driving Vehicles (N=44).

There has been much speculation that with self-driving vehicles, there would be a lot of occupant-free cars on the road because usage would be as shared vehicles—in fleets or within households. But at this early stage in market development, such concepts are not top of mind. The majority of respondents who were interested in owning a self-driving vehicle indicated they

would use their self-driving vehicle in the same way as a conventional vehicle—to travel to and from work, errands, and shopping, and to visit family and friends. Only a few people mentioned anything out of the norm. They did not fully grasp the new opportunities that might unfold with ownership of a self-driving vehicle. One individual assumed that an insurance discount would be given because of its enhanced safety functionality, and so he would have his teenage son take the self-driving vehicle. Another said, "I'm the less confident driver, so I would use it." A couple mentioned that their young children could use it to go to school.

There has also been speculation that people might be interested in purchasing large, multi-purpose vehicles with amenities for work and play, but most respondents did not envision changing vehicle size if they were to purchase a self-driving vehicle. Regardless of the size of the personal vehicle that they drive most now (e.g., compact, mid-size, full-size, mini-van, or large SUV), they would consider the same size in purchasing a self-driving vehicle. Five people recognized the social opportunities inherent in self-driving vehicles, and indicated that they would purchase larger vehicles as a result (from compact or mid-size). Three people said they would reduce their primary vehicle size (from a mid-size or full-size).

Factors Influencing Intention to Own

An important factor in people's intention to own a self-driving vehicle was convenience:

- "Convenient to have it when I needed one."
- "For having it there when I needed it and not having to call someone."
- "[There are the] same negatives associated with shared vehicles as with public transit like convenience of access and egress."
- "More freedom to do other things while on my trips."
- "Would not be interested in using it just here and there. Would want it as my vehicle to use whenever I need it."
- "If it got to the point where the great majority of the cars on the road were self-driving cars (like Ubers or car shares), then maybe car share but for now it seems inconvenient."

Also mentioned as a factor in whether people would own or car share was price. While most people thought car sharing would be less expensive (see the subsection "Interest in Shared Self-Driving Vehicles"), a few thought it would be less expensive to own:

- "The cost—would like a discount for new users."
- "If there were a sharing option, I think it would be more expensive. They take their cost plus a profit."

Only one or two people mentioned liability, legislation, vehicle size, brand, or rules of the road. On the latter, law enforcement rules were mentioned: "Can I drink and have the vehicle drive me home?"

Willingness to Pay for Vehicle

In answer to the question, how much extra would you be willing to pay to own a self-driving vehicle above the average price of a new vehicle—which was about $32,000 in 2014—by far the most frequent response was "a slight amount" as compared to "zero" or a "great amount." Categorical response options were used for the question rather than monetary units because the technology is so new that answers with exact monetary figures would not be reliable. The information gathered in this question provides insight into the intensity of desire to own and the value placed on self-driving vehicles. That few would be willing to pay a great amount suggests that consumer demand for self-driving vehicles may be soft at present.

Respondents gave varying reasons to support their willingness to pay just *a slight amount* above the average price for a new vehicle. Some people recognized that the technology "has to cost something." They said:

- "I've generally been willing to pay a small premium for some technologies."
- "I look at this as an option on the vehicle."

A few recognized that this specific technology was of value to them:

- "Because not having to drive myself is worth something to me."
- "I think it would be worth it. I'm getting older. I cannot get out on the road as I used to."

There were those who could see the value, so they did not say zero, but cost was a factor:

- "Budget constraints. Same reason I don't own a hybrid car."
- "Retired; do not think I could afford an expensive car."

Others did not want to pay for something that was like a novelty to them:

- "Do not have a great need for it; it would be more like a toy. With that, I would not want to pay a whole lot more."
- "I don't know if the convenience would justify a big increase in cost."

Two people said that they would pay a "great amount more." Their reasons were tied to perceptions that the "technology does not come cheap." One said, "I would expect a 30 to 50 percent increase." Two people said that they would pay "zero." One focused on how quickly autos depreciate in value: "It goes down in value very fast. Just not worth the extra money." The other factored in the related expenses of upkeep and maintenance.

Interest in Shared Self-Driving Vehicles

Many people have speculated that car sharing will be the primary business model for self-driving vehicles. However, among the Austin respondents, fewer were interested in using a shared self-driving vehicle—like Zipcar, Car2go, or Uber taxi—than in owning one (41 percent and 59 percent, respectively). There were no age or income effects that were associated with interest in car sharing. Two categories of reasons underpinned this choice: gaining experience and cost.

Gaining Experience and Cost

By far, most people said that they would want to "try it out to see if I like it." They would not want to invest in one before experiencing it:

- "To start with, I would do the car share just so I could get experience and gain trust in the vehicle."
- "Would first want to see how they work and if I liked them."
- "I already have a vehicle, but it would be nice to have the option of not having to drive myself on long trips."

Others were budget conscious:

- "The tradeoff of sharing compared to owning a car would be cheaper."
- "Would rather pay for a vehicle when I need it than have to worry about all the upkeep."
- "It would be costly to own one, and it would take years to get an older model."
- "More practical method. If you are not going to control the vehicle, why not use as a mass usage."

Willingness to Pay for Shared Vehicles

In answer to the question, "How much extra would you be willing to pay to access a self-driving car-share vehicle above the average rate of $10 per hour?" by far the most frequent response was "a slight amount" as compared to "zero" or a "great amount." The main rationale was that they understood that, as a new technology, the cost of accessing a self-driving car share would go up, but they felt there would be cost savings from the economies of scale associated with car sharing and being driverless. One person said, "You are replacing human labor with a computer, so it should not go up too much. When things first come out, they are usually more."

Three people said they would pay a great amount more. For example, one said, "I would pay double. I would not use it all day since it is by the hour. Would make it worth it."

Two people said they would pay zero, basically because "I am cheap."

Regardless of their willingness to pay, many people assumed that, with time, "the price would go down."

Impact on Number of Vehicles Owned

One theory concerning self-driving vehicles is that households will reduce the number of vehicles owned because of the capability to share cars within the household: a self-driving vehicle, for example, could take one worker in the household to work, return to take the second worker, and then ferry children to school (*7*). The auto would not be sitting idle during the day in a workplace garage. Interview respondents were asked, "You currently own X number of cars. How would that change if self-driving vehicles were available today?"

In terms of vehicle ownership, three of five respondents (61 percent) indicated that being able to own or access a self-driving vehicle would cause no change in their current vehicle ownership, whereas 23 percent indicated they would reduce the number of vehicles owned. A smaller percentage (16 percent) said they would increase the number of household vehicles (see Table 10).

Table 10. Change in Number of Vehicles Owned (N=44).

	Current Number of Vehicle Owned				
	Zero Vehicles	One Vehicle	Two Vehicles	Three or More Vehicles	Total
No change	1	9	14	3	27 (61%)
Reduce	0	2	5	3	10 (23%)
Increase	1	4	0	2	7 (16%)
Total	2	15	19	8	44 (100%)

Respondents who answered "no change" tended to report that they would switch out a conventional vehicle for a self-driving vehicle. Most did not conceive of being able to share the same self-driving vehicle with other household members:

- "We each need to have our own cars because our schedules are different."
- "[We] need both cars. I work, and my wife takes kids around."
- "She needs a car, and I need a car."
- "[We] would get rid of our oldest vehicle and have the self-driving for a back-up if we needed to do two different things at the same time."

People who responded "reduce" did consider the special aspects of self-driving cars: "If it had the ability to take me to work and go home for her to use for the day and come back to get me at the end of the day, [we] would reduce to one vehicle."

Others suggested that they would reduce a vehicle and use the "car-sharing program."

The few who said they would increase would add a self-driving vehicle to their existing stock. In their minds, it would be like adding a special utility vehicle:

- "I might increase to add the self-driving vehicle that could take my son around and still have [the normal] vehicle to run errands."
- "I would keep my truck for pulling my boat."
- "[I] would keep my car now and get the self-driving vehicle. It would be less wear on the vehicle and use the older one when I have time."

Impact on VMT

It is very uncertain if self-driving vehicles would increase or reduce VMT. Some speculate that people would live farther away from work or school because they could do other activities while on their commutes, which would increase VMT per capita. Others believe that self-driving vehicles will be making lots of zero-occupant trips because owners would not want the vehicles to sit idle, which would add to overall VMT. The assumption also exists that the mobility challenged (e.g., elderly or impaired) would travel more often, and that this too would increase VMT. On the opposite end of the spectrum, some believe that self-driving car-sharing programs will decrease VMT per capita, as has been found with conventional car-sharing programs (*8*).

In the online survey, 16 percent of respondents indicated that they drove less than 5,000 miles in 2014, 35 percent reported driving 5,000 to 10,000 miles, 35 percent reported driving 10,000 to 15,000 miles, and 15 percent reported driving more than 15,000 miles in 2014.

In the follow-up, interview respondents were asked, "You now drive X miles in an average week. How would that change if self-driving vehicles were available today?" Most (66 percent) said their annual VMT would stay the same; 25 percent indicated it would increase (see Table 11). Respondents were mostly vehicle drivers. There was only one person who took public transit. None of these individuals had any disability preventing them from driving or were currently non-drivers. Researchers did not find an age effect in terms of a reported increase in VMT. Those people age 66 and older were no more likely to increase their VMT than other age groups.

Table 11. Change in VMT (N=44).

	Current VMT				
	Less than 5,000	5,000 to 10,000	10,000 to 15,000	More than 15,000	Total
Stay the same	3	4	10	12	29 (66%)
Increase	1	6	3	1	11 (25%)
Decrease	0	2	1	1	4 (9%)
Total	4	12	14	14	44 (100%)

People who believe their VMT would "stay the same" do not believe that self-driving vehicles will change their routines, their routes, or their activities:

- "Daily routine would not change."
- "I do not see doing anything different than I normally do."
- "[I] will not change my habits just because I have a car that takes me places."

On the other hand, the people who answered "increase" did think that having a self-driving vehicle would induce travel. Some of this travel would be long-distance or leisure travel, but local travel might increase as well:

- "I would go on more trips since I would not have to drive."
- "We might take longer day trips. The car could take us there and back."
- "[Automated vehicles would] give us flexibility to visit friends and family out of town. [We] could go downtown more."
- "[I] turn down a lot of things because I do not want to drive."
- "[I] might go out more. [I] could nap on the way there."

The primary reasons that a few people said they would drive less are they would use car sharing or their travel would probably go from points A to B more efficiently.

Impact on Residential Location

Much speculation surrounds whether people with access to self-driving vehicles would relocate to residences farther from where they work. Most of the sample (80 percent) said they would not change where in the Austin region they live today. People choose where they live for a variety of reasons: price, schools, neighborhood amenities, public services, etc. Access to a self-driving vehicle, at least under their current knowledge of the travel opportunities such a vehicle would bring, would not change their location choice: "I would not move for a car."

Nine people said they would change where they live. Of these, most would move farther out:

- "[I] might move farther out to get more house for the money and be productive and less stressed on the way to work."
- "[I would] be able to live farther out but with the convenience of a self-driving car."

Two people indicated that they would move closer to downtown Austin:

- "I would want to live in the city closer to public services as I get older. I do not like driving in the city now."
- "Car-share services would more likely be in Austin, so I would need to be closer."

Impact on Long-Distance Travel

Of the 44 respondents, 57 percent said they occasionally make inter-city trips in Texas, and 43 percent said they frequently make them. When asked if the mode of travel for inter-city trips would change if self-driving vehicle were available today, 45 percent said they would change. But while the mode would not change, trip frequency would:

- "I might travel more frequently and to different destinations."
- "I would be willing to make more trips."
- "I would probably be going on more trips since I wouldn't have to be the driver."

Most of the respondents' travel is in vehicles as a driver or passenger. Only three people said they mostly use air, and of these, two would not change their behavior if self-driving vehicles were available.

These people were also asked if their mode of travel would change for trips outside of Texas. Most people (76 percent) currently travel outside of Texas by air. Forty-two percent said they would change their mode of travel. Most people said they would probably take the self-driving vehicle more for these trips (rather than air) if the car was fuel efficient and they had the time for the drive:

- "I would probably travel in self-driving vehicles. I could see more, and it may be cheaper than flying."
- "If it were close enough where the fuel expense was less than a plane, I would take the vehicle."

Of the people who would not change from air travel to the self-driving vehicle, the main reasons were time and distance:

- "I don't have the time to drive—[it takes a] full day to drive somewhere and to drive back."
- "Because of the distances involved."
- "Time factor; time issues."

Modeling AV Impact on Travel Demand

Because of the transformative nature of AV technology, this study attempted to quantitatively *model* the impact on traffic and congestion in the Austin region by answering these questions:

- How might self-driving vehicles on roadways impact traffic and congestion?
- Will people drive more if their vehicle is automated?
- How will people value their travel time if they have AVs?
- Will the travel time be less onerous with the introduction of automation?

Answering such questions is challenging for a number of reasons. As an emerging mode of transportation and a brand-new technology, AVs bring a high level of uncertainty to the field of travel-demand modeling.

Travel-Demand Forecasting Models

Travel-demand forecasting models attempt to replicate the real travel environment, and are used to estimate travel behavior and resulting demand for a specific time in the future. These models help answer the challenging "what if" policy questions, such as "How might addition of a new transit line impact traffic congestion on a specific route?" Travel forecasting models are computer models—they are complex, based on various assumptions, and built through mathematical formulas. These models are often in need of large amounts of data, and the process of model development starts with the collection of *observed* data. Given that AVs are not yet part of the transportation system, no observed data are yet available to build (or validate) such forecasting models.

Researchers and agencies have thus been challenged with the question of how to incorporate this new mode of travel into the transportation models to *accurately* estimate the traffic-related impacts. A recent study by Guerra (*9*) revealed that only two of the 25 largest metropolitan planning organizations (MPOs) in the United States mentioned automated or connected vehicles in their long-range transportation plans. The study results reveal that MPOs are not yet sure how to plan for and model this future. Apparently, neither the models nor the data yet exist to answer the various questions being raised, but researchers are eager to produce some answers to kick-start future scenarios. The last several years have witnessed attempts to adopt or advance the currently used methodologies to test different automation scenarios, as briefly described in Appendix B. More frequently, these studies applied simpler techniques to offer rough estimations of AV impacts.

Future Projections of Impact on Travel Demand: A Test Case Using CAMPO Model

Keeping in mind all the complexities and uncertainties but using the insights obtained from the survey results, a similar approach was undertaken using the Capital Area Metropolitan Planning Organization (CAMPO) 2010 travel-demand forecasting model developed for the Austin region. The details of this modeling exercise are documented in Appendix C.

The CAMPO travel-demand model is founded on a trip-based approach, which uses individual trips as the unit of analysis. The trip-based approach uses a traditional four-step process:

1. Trip generation—estimates the number of trips that will be made.
2. Trip distribution—estimates where the trips will likely go.
3. Mode choice—estimates how the trips will be divided among the available modes of travel.
4. Trip assignment—estimates the routes that the trips will likely go.

Among these four components, the question of interest (i.e., how the emerging mode of self-driving vehicles will influence travel) can be evaluated within the *mode choice* step of a trip-based model. This step uses mathematical expressions to allocate trips to the mode people will likely use to travel between their origins and destinations and, by extension, how those choices affect the overall travel in the region. When people are making decisions on which travel mode to use, their decisions are influenced by several factors, such as travel alternatives (e.g., travel time, travel cost, walk access distance, transfers required, or transit fare) or individual and household characteristics (e.g., income, age, number of vehicles owned, or number of children in the traveler's household).

While individuals might place different importance on such variables, travel time has always been identified as one of the most important factors adversely influencing their choice of travel mode. The longer the travel time, the less likely an individual will choose the corresponding mode of travel. This provides a key measure in evaluating the impact of AV technology.

As discussed in the previous sections, people responding to the survey generally indicated positive attitudes toward AVs. While the reasons varied, one of the potentially applicable results was related to the more relaxing and carefree environment that they envision while traveling without the need to drive. Respondents also indicated that time spent in the car could be more productive. The perceived benefits of the more relaxed, more productive travel options offered by AVs could lead to a decrease in the perceived travel time penalty, particularly for drivers. Thus, the long travel times spent in cars might not be that much of a concern with self-driving vehicles.

Assuming that the travel time will be less onerous with the introduction of automation, different scenarios were tested in the CAMPO model by reducing the sensitivity of travelers to the time they spend inside the vehicle. While results varied by the levels of sensitivity that were tested

under different scenarios, the results suggest three main findings. As the sensitivity of individuals to the time spent inside the vehicle is reduced, the model results suggest the following:

- Total daily VMT shows a slightly increasing trend.
- Individuals drive more—the total number of auto trips shows an increasing trend across all categories of auto trips but especially for trips made for home-based work and home-based education purposes.
- Individuals use less transit—the total number of transit trips shows a decreasing trend especially for reliance on the local bus.[1]

Many urban regions suffer from continuing increases in traffic congestion and more time spent traveling. Longer travel times increase traveler frustration, which could lead to changes in individuals' behaviors, such as shifting to other modes of travel. However, if travel time is less burdensome and more enjoyable, individuals might care less about the time they spend inside the vehicle. Based on the survey results, this can be achieved by self-driving vehicles given the more relaxing and productive travel time the survey respondents assumed would be the case. Based on the model results, such a positive view toward travel time might also indicate a willingness to travel more miles or shift from reliance on transit to a personal auto. An individual might be more willing to tolerate longer travel time if there is congestion since they can use that time more productively and might find the other alternatives, such as taking a local bus, less attractive. This might consequently increase traffic and congestion in the region.

The model results presented here should be evaluated with caution. Besides the data limitations that might prevent obtaining accurate representation of the changes under AV scenarios, the trip-based models (as in the case of the CAMPO model) fall short in responding to policy-sensitive questions that require more behavioral realism, such as how new technology will impact travel behavior. The need for realistic representations of behavior (instead of statistical aggregation of trips) has precipitated a shift in the planning profession from trip-based approaches to more behavioral approaches in travel-demand modeling. Behavioral models might be especially helpful in responding to the shorter-term congestion management policies or in understanding transformations in an environment with new travel options.

Estimating congestion impacts of AVs in the Austin region requires a complex set of structural changes in the CAMPO model. However, *the main limitation in confidence of the model results is the lack of observed data for this emerging AV technology*, regardless of the modeling approach. The results provided here are intended to serve as a starting point for discussion regarding the broader impacts of implementing AV technology in Austin.

[1] Please see Appendix C for more detailed technical information on the model results.

Conclusions

How Likely Are People to Use Automated Vehicles?

The sample was evenly split on intent to use self-driving vehicles, with half likely and half unlikely to use them. This is indicative of the early stages of research into the topic and the fact that the public is aware of but not very knowledgeable about self-driving vehicles. As knowledge increases, it is reasonable to expect the results to tilt in one direction or the other. Many transportation experts expect that the public will tilt toward acceptance and use of self-driving vehicles.

In the survey sample, nearly 7 out of 10 people were in a wait-and-see position, with 36 percent "somewhat likely" to use and 32 percent "somewhat unlikely" to use. Narrow slices of the sample had definite views, with 18 percent being "extremely unlikely" to use and 14 percent being "extremely likely" to use. A segmentation scheme was developed to portray the differences in acceptance and intent to use: Rejecters (extremely unlikely), Traditionalists (somewhat unlikely), Pragmatists (somewhat likely), and Enthusiasts (extremely likely).

The top reason someone was unlikely to use was lack of trust in the technology, and this factor has also been observed in previous research although stated in other ways.

What Are the Factors That Influence Acceptance and Intent to Use?

Further analysis showed that intent to use was higher in some population segments. Interestingly, age was not a significant factor in intent to use, nor was household income. While vehicle ownership per se was not a significant factor, currently owning a vehicle with highly automated features was significant in intent to use. Because people have gained trust in the automated features performing appropriately on the vehicles they own now, they may be predisposed to believe that the self-driving vehicle will perform as required.

Psycho-social variables were important to acceptance and intent to use. A person's position on the adoption curve was highly correlated with intent to use: Early Adopters were likely Enthusiasts or Pragmatists, and Laggards were likely Rejecters or Traditionalists. Variables such as perceived safety benefits and data privacy were significant in adoption, and the research supports these findings. The more concerned a person was about data privacy issues, the lower his or her intent to use self-driving vehicles. However, desire to feel in control was not associated with intent to use.

A regression model was used to identify the significant predictors of intent to use from among the various demographic, behavioral, and psycho-social variables in the study. The model results indicate the only demographic variable associated with intent to use was having physical conditions that prohibit driving. Other variables were psycho-social, such as thinking that using self-driving vehicles would be fun, that there would be a decreased accident risk, and that it would be easy to become skillful at using self-driving vehicles. Unsurprisingly, such findings

suggest likely users focus on personal benefits rather than societal benefits. There is also an underlying social aspect to intent to use. Use of social media technology (i.e., text messaging and Facebook) was a stronger predictor than the use of conventional technology, such as emailing and online searching. Social influence was also a strong determinant. This may stem from the car often being regarded as a status symbol, which highlights the connection between intent to use and the social environment.

What Is the Appeal of Self-Driving Vehicles for Consumers?

Those who were likely to use self-driving vehicles were asked, "Why?" While the reasons varied from person to person, the most frequent answers were that the vehicles would:

- Be safer than human drivers.
- Relieve stress of driving.
- Allow people to be productive while traveling in a car.
- Be like using public transit but better.
- Be the wave of the future.
- Be a mobility enabler for aging seniors.
- Be adequately tested before being placed on the market.

In the same vein, words that likely users used to describe the experience were *carefree*, *relaxing*, and *convenient*; only a few said they would be nervous. Generally, people who currently think they would be likely to use these vehicles view the experience as a positive change. Their biggest worries relate to self-driving system malfunctions or glitches. The questions they had about the technology emphasized that people may be aware of the new technology but not very knowledgeable about it.

In What Ways Would People Change Their Current Travel Behavior?

People can access self-driving vehicles in two ways: personal vehicle ownership or use as a shared vehicle, like an Uber taxi or Zipcar. Private ownership was preferred over car sharing by a 3 to 1 margin. For this Austin sample, the shared mobility market was not the desired choice, even though it may be how some self-driving vehicle providers see the market developing.

This research did not reveal the dramatic impacts on travel behavior about which people have speculated, at least not at this point in time when knowledge and experience with the technology are so limited. Most respondents said they would not change their vehicle ownership, VMT, or residence location. Anticipating that people would have a difficult time conceiving of possible changes for a technology they have not experienced, qualitative interviews were conducted, enabling interviewers to clarify and probe respondents' answers.

In terms of vehicle ownership, in 2012, there were two vehicles per household (median) in Austin. There would be almost no change in the number of vehicles owned due to self-driving vehicles because, at this point in time, most people said that they would switch out one of the

conventional vehicles they own for a self-driving one. These people did not conceive of the self-driving vehicle as being able to do double duty within a household.[2] Currently, only about 5 percent of households in Austin have zero vehicles. These survey data do not indicate that this number will grow.

Average annual VMT would stay about the same as well, which was about 25 miles per day per capita. People did not think their routines, their routes, or their activities would change because of the availability of self-driving vehicles. About one in four persons thought their VMT would increase due to induced travel, much of it long-distance or leisure travel. Few if any could conceive of reducing their VMT; those who did cited car sharing as the reason. Few people would change their residential location because of access to a self-driving vehicle; only a small share of respondents would move farther out to get more house for the money. Some would move closer to downtown to access self-driving car-sharing services, which they believe will be more prevalent in the central city.

Most people could envision large changes in their long-distance travel behaviors when they gain access to a self-driving vehicle. Many respondents felt they would increase the frequency of their long-distance (inter-city) trips. In a future world of self-driving vehicles, one could conceive of more long-distance travel by vehicle beginning and ending in Austin—both of which would impact current conditions.

How Might Self-Driving Vehicles on Roadways Impact Traffic and Congestion?

Despite the model's coarseness at modeling traffic and congestion impacts from AVs, it did show that the new vehicle technologies will likely increase VMT and decrease transit use.

The conventional view of transportation planners and modelers is that travel is a derived demand—not pursued for its own sake but mainly as a means of accessing desired activities in other locations. In other words, people want to do activities and must travel to reach these activities, but they try to minimize the travel while reaching the desired destination.

Because AVs appear to mitigate the penalty of travel, there is the likelihood that travel (VMT) will increase in the future. Additionally, travel in personal vehicles will likely increase, resulting in a reduction of travel by public transportation.

Summary

These results provide some of the first data on the types of people likely to use self-driving vehicles and their rationale. Since self-driving vehicles are not currently commercially available, it is impossible to verify that intention to use will correlate with actual usage. The correlation

[2] Double duty in this context means serving the mobility needs of multiple persons in the household because the vehicle could drive itself to and from pick-up and drop-off locations.

across a variety of studies in different fields indicates that the CTAM model, used in this study, is capable of predicting actual use and lends credibility to the research approach and findings.

This study began by laying out basic questions about future demand for self-driving vehicles and its impact on travel behavior. These vehicles are not yet on roadways, and so it was challenging to capture reliable and accurate information about people's intent to use and their behavioral responses to its use. Nonetheless, planning for publicly provided goods and services demands collecting such information to grow an evidence base on likely impacts. That said, while respondents were aware of the concept of self-driving vehicles, they were not very knowledgeable about them. Researchers and policy makers are looking for specific impacts on travel behavior, but it is difficult for early research to identify them because the general public is not yet familiar with the new opportunities (or challenges) self-driving vehicles may bring, such as intra-household car sharing, new types of car-sharing fleets, or the challenges of mixed fleets on the road.

This methodology was designed to account for the fact that large portions of the general public are uninformed about self-driving vehicles, and this research points out the lack of public education and outreach on the topic. Realizing that public opinion polls are not substitutes for thought, this study used a two-phased approach of online survey and face-to-face interviews, which was effective. By having people answering questions in a qualitative manner, researchers were able to learn about the respondents' misconceptions or uncertainties with the technology. This information will be useful for future studies that could replicate this survey within a larger population, such as that of Texas or the nation, to determine whether the findings will remain consistent with a diverse population. The Austin metropolitan statistical area may not be representative of all potential users of self-driving vehicles. Also, future research needs to assess how the determinants perform over time. Acceptance and adoption may be conceived as an experiential factor, and as the vehicles become available, the determinants may change.

Appendix A: Research Methodology

A two-part study was used to investigate the potential uptake of self-driving and how this might impact travel behavior. Given the fact that self-driving vehicles are a new technology with which respondents would have no actual experience, both quantitative and qualitative methods were used. In the first part, data were collected via an online survey, and in the second part, data were collected in qualitative, face-to-face interviews. Figure 4 shows the conceptual framework for the research approach. The research protocol was approved by the Institutional Review Board of Texas A&M University.

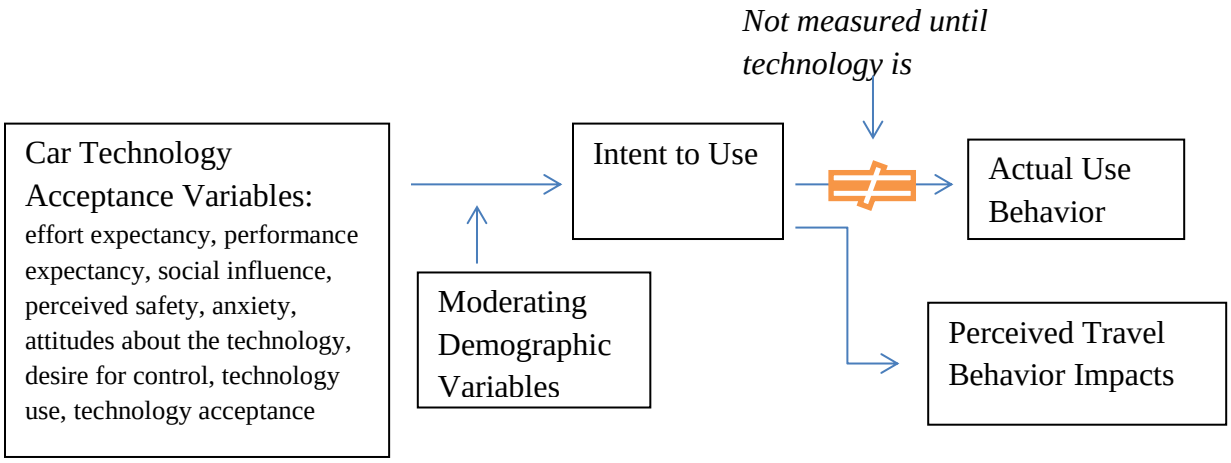


Figure 4. Conceptual Framework for Research Approach.

Online Survey

The survey was conducted in May 2015 using ResearchNow, an online sample provider, to target and recruit potential respondents in metropolitan Austin, Texas, that were distributed among four age categories: less than 30, 30–45, 46–65, and 66 and older. Non-probability sampling was used to select the respondents; the results are not meant to be generalizable to Austin as a whole but to present information about the distribution of opinions, preferences, attitudes, and behaviors among the survey sample. In total, 556 people completed the online survey, which took an average of 12 minutes to complete. A 35-question survey was created and placed on the ResearchNow platform. Questions addressed several factors, including:

- Intent to use self-driving vehicles.
- Demographic items (gender, age, travel-restrictive medical conditions, income, education, household size, presence of children, and zip code).
- CTAM variables (effort expectancy, performance expectancy, social influence, perceived safety, anxiety about self-driving vehicles, attitudes toward self-driving vehicles, and perceived safety).
- Personality scales (desire for control, technology acceptance, and technology use).

- Travel behavior variables (vehicle owned/leased, automated features on the vehicle, employment and student status, commute mode, driver's license, use of new transportation services, and VMT in 2014).
- Other potential influencing factors (privacy concerns and adoption curve).

After the first 10 questions, a six-sentence paragraph described self-driving vehicles and prompted respondents to view a two-minute video on self-driving vehicles before continuing with the next questions. After the last question, respondents were asked if they would be willing to participate in a 30-minute interview on the topic of future travel behaviors, with a $50 incentive.

Results of the Survey

A description of the online survey sample follows. Of the 556 online survey respondents, 24 percent were less than 30 years old, 28 percent were between 30 and 45 years old, 30 percent were between 46 and 65 years old, and 18 percent were more than 65 years old. Forty-two percent of the sample was male, and 58 percent was female. The household income distribution for the sample was comparable to the population distribution for the Austin region, while educational attainment was slightly skewed toward higher educational attainment.

Sixty-four percent were employed full- or part-time. Most respondents commuted to work as a vehicle driver (85 percent), 5 percent as a vehicle passenger, 6 percent by public transit, 3 percent by telecommute, and <1 percent by walking. Twelve percent were full- or part-time students. Half (50 percent) traveled to school as a vehicle driver, 19 percent by public transit, 10 percent by walking, 1 percent by biking, and <1 percent as a vehicle passenger. Fifteen percent attended an online school and thus telecommuted. Ninety-four percent currently own or lease a vehicle, and 97 percent have a driver's license. The main reason cited for not owning or leasing a vehicle was the affordability of the purchase price. When asked how often they drive a motor vehicle, 74 percent said every day, 20 percent a few days a week, and 6 percent a few days a month or almost never. Two percent reported a physical condition that prevented them from driving.

Respondents were asked about their use of new transportation services during the previous week. Twenty-six percent had used smartphone transportation apps like Waze, Metropia, Ridescout, and Google Maps; 8 percent had used taxi services, including Uber and Lyft; 1 percent had used ridesharing services like Carma or Ridejoy; and 1 percent had used car-sharing services like Zipcar and Car2go. Eighty percent of respondents had heard about self-driving vehicles prior to participating in the survey, and 26 percent reported that their vehicle has automated features such as adaptive cruise control, automated lane keeping, or automated parking assist.

Questionnaire

Informed Consent

You are invited to take part in an online survey conducted by the Texas A&M Transportation Institute and funded by the State of Texas.

The purposes of this study are to examine the factors that might influence people's future use of self-driving vehicles and how high levels of vehicle automation could affect the ways in which people will choose to travel in the future. This survey will take about 10 minutes to complete. The questions that you will be asked to answer pose no more risks to you than you would come across in everyday life. Aside from your time, there are no costs for taking part in the study.

Information about you and related to this study will be kept confidential to the extent permitted or required by law. People who have access to your information include the Principal Investigator and research study personnel. Representatives of regulatory agencies such as the Office of Human Research Protections and entities such as the Texas A&M University Human Subjects Protection Program may access your records to make sure the study is being run correctly and that information is collected properly.

You may contact the Principal Investigator, Dr. Johanna Zmud, for study details or to tell her about a concern about this research at 512-407-1140 or j-zmud@tti.tamu.edu. For questions about your rights as a research participant or if you have questions, complaints, or concerns about the research, you may call the Texas A&M University Human Subjects Protection Program office at 979-458-4067 or toll-free at 1-855-795-8636, or email irb@tamu.edu.

If you would like to take part in the study, please continue by clicking the "Next" button below.

1. What is your gender?

Male	1
Female	2
Other	3

2. What is your age? _____

3. Do you have any physical conditions that prohibit you from driving?

Yes (specify) _____	1
No	2

4. How well do the following statements describe you? Record a "1" for very untrue of me, a "2" for somewhat untrue of me, a "3" for neutral, a "4" for somewhat true of me, and "5" for very true of me.

I enjoy making my own decisions	_____
I prefer to do something about a problem than to sit by and let it continue	_____
I would rather someone else took over leadership role on a group project	_____
When it comes to orders I would rather give them than receive them	_____

5. How much do you agree or disagree with the following statements? Record a "1" for strongly disagree, a "2" for somewhat disagree, a "3" for neither agree nor disagree, a "4" somewhat agree, and a "5" for strongly agree.

It is important to keep up with the latest trends in technology _____
New technology makes people waste too much time _____
New technology makes life more complicated _____
Technology will provide solutions to many of our problems _____

6. How often do you use the following technologies? Record a "0" for Never, a "1" for few times a year, a "2" for several times a month, a "3" for several times a week, a "4" for several times a day, and a "5" for several times an hour

Smartphone usage _____
Facebook usage _____
Internet shopping _____
Other Internet searching _____
Emailing _____
Text messaging _____
Video gaming _____
Smartphone transportation apps _____

SKIP to Q8 IF "NEVER" TO ALL Q6.

7. How concerned are you about privacy when using the internet or internet-enabled technologies?

Not at all concerned 1
Somewhat concerned 2
Moderately concerned 3
Extremely concerned 4

8. When it comes to adopting new technology, in which category do you fall on the adoption curve—early adopter, late adopter, or laggard?

Early adopter—I am among the first of my friends to adopt new technology 1
Late adopter—I wait awhile before adopting new technology 2
Laggard—I am among the last of my friends to adopt new technology, if I adopt at all 3

9. Do you currently own or lease a vehicle*?*

Yes—I own or lease a vehicle 1
No—I do not own or lease vehicle 2 SKIP TO VIDEO

10. Does the vehicle that you currently own or lease have with automated features, such as adaptive cruise control, automated lane keeping, or automated parking systems?

Yes 1
No 2

****
In our study, we are interested in your opinions about self-driving vehicles. You may be able to buy a self-driving vehicle from major manufacturers or access one through a car-sharing service within the next 5–8 years. A self-driving vehicle is a vehicle that controls all driving functions for an entire trip, including steering, braking, and acceleration. It covers freeway driving, neighborhood driving and activities like parking. The "operator" provides destination or navigation input, and is in the vehicle to take over control of the vehicle if conditions warrant. The market push for self-driving vehicles is to make driving safer and more efficient.
Please watch the following video on self-driving vehicles before continuing with the next questions. https://www.youtube.com/watch?v=cdgQpa1pUUE
****

11. Have you ever heard of self-driving vehicles before participating in this survey?

Yes	1
No	2
Don't know	3

12. How well do the following statements describe you? Record a "1" for very untrue of me, a "2" for somewhat untrue of me, a "3" for neutral, a "4" for somewhat true of me, and "5" for very true of me.

I would find self-driving vehicles useful in meeting my driving needs _____
If I were to use self-driving vehicles, I would feel safer on driving trips _____
I would be proud if people saw me using a self-driving vehicle _____
People whose opinions I value would like using self-driving vehicles _____

13. How well do the following statements describe you? Record a "1" for very untrue of me, a "2" for somewhat untrue of me, a "3" for neutral, a "4" for somewhat true of me, and "5" for very true of me.

I have concerns about using self-driving vehicles _____
Self-driving vehicles are somewhat frightening to me _____
Learning to operate a self-driving vehicle would be easy for me _____
Interactions with self-driving vehicles would be clear and understandable to me _____
It would be easy for me to become skillful at using self-driving vehicles _____

14. How much you agree or disagree with the following statements? Record a "1" for strongly disagree, a "2" for somewhat disagree, a "3" for neither agree nor disagree, a "4" somewhat agree, and a "5" for strongly agree.

Using a self-driving vehicle is a good idea _____
Self-driving vehicles make driving more interesting _____
Using a self-driving vehicle would be fun _____
Using a self-driving vehicle would decrease accident risk _____

15. Imagine that *self-driving vehicles were on the market now either for purchase or rental*. What is the likelihood that you would ride in a self-driving vehicle for everyday use?

Not at all likely	1
Somewhat unlikely	2
Somewhat likely	3 SKIP TO Q 17
Extremely likely	4 SKIP TO Q 17

16. What is the main reason you would be unlikely to ride in a self-driving vehicle for everyday use?

Safety	1
Cost	2
Insurance/liability	3
Lack of trust in technology	4
Or something else:_____	5

17. What is your current level of employment?

Employed full-time	1
Employed part-time	2
Not currently employed	3 SKIP TO Q 20
Retired	4 SKIP TO Q 20

18. How did you usually get to work last week? The single mode of travel used for the longest distance to your primary job.

Vehicle driver	1
Vehicle passenger	2
Public transit	3
Walk	4 SKIP TO Q 20
Bike	5 SKIP TO Q 20
Telecommute (work at home)	6 SKIP TO Q 20

19. Is this a vehicle owned by…

Your household	1
A friend or relative	2
Car-sharing service (e.g., Zipcar, Car2go)	3
Ridesharing service (e.g., Carma Carpooling, Ridejoy)	4
Taxi service (e.g., Uber, Yellow cab)	5

20. Are you a full or part-time student?

Full-time student	1
Part-time student	2
Not a student	3 SKIP TO Q 23

21. How did you usually travel to school last week? The single mode of travel used for the longest distance each day.

Vehicle driver	1
Vehicle passenger	2
Public transit	3

Walk	4 SKIP TO Q 23
Bike	5 SKIP TO Q 23
Telecommute (online school)	6 SKIP TO Q 23

22. Is this a vehicle owned by…

Your household	1
A friend or relative	2
Car-sharing service (e.g., Zipcar, Car2go)	3
Ridesharing service (e.g., Carma, Carpooling, Ridejoy)	4
Taxi service (e.g., Uber, Yellow cab)	5

23. Including yourself, how many individuals live in your household?

One	1
Two	2
Three	3
Four or more	4

24. How many children less than 16 years of age live in your household?

None	1
One	2
Two	3
Three or more	4

25. How many motor vehicles does your household own or lease?

None	1
One	2 SKIP TO Q 27
Two	3 SKIP TO Q 27
Three or more	4 SKIP TO Q 27

26. Which of the following reasons best describes why you don't own or lease a motor vehicle?

Affordability of purchase price	1
Ongoing operational/maintenance costs	2
Lifestyle needs met by walking, biking, and other transportation options	3
Can't drive—for whatever reason	4
Or something else:_____	5

27. Do you have a current driver's license?

Yes	1
No	2

28. Did you use any of the following transportation services last week? (select all that apply)

Carsharing services, like Zipcar or Car2go	1
Ridesharing services, like Carma, Carpooling or Ridejoy	2
Taxi services, like Uber or Yellow Cab	3
Transportation apps, like Waze, Roadify, Metropia, Ridescout, Google Maps	4
Public transit services, either bus or rail	5
Transportation service for senior or disabled	6
None of the above	7

29. How often do you drive a motor vehicle?

Every day	1
A few days a week	2
A few days a month	3
Almost never	4

30. About how many miles did you drive in 2014?

Less than 5,000	1
5,000 to 10,000	2
10,000 to 15,000	3
More than 15,000	4

31. In what zip code do you live? __ __ __ __ __

32. What is the highest degree or level of school you have completed?

Grade 12 or less	1
High school graduate	2
Associate's degree or some college	3
Bachelor's degree (e.g., BA, BS)	4
After Bachelor's degree (e.g., MA, MS, MD, JD, Ph.D.)	5

33. What category best describes your total household income for last year (2014)?

Less than $24,999	1
$25,000 to $49,999	2
$50,000 to $99,999	3
$100,000 to $149,999	4
$150,000 or more	5

34. How much did viewing the video influence your intention to use a self-driving vehicle?

Extremely	1
Somewhat	2
Not at all	3

35. Would you be willing to participate in a 30-minute qualitative interview on the topic of your current and future travel behaviors? You would receive a $50 as compensation for your time.

YES	1
END OF SURVEY, THANK YOU VERY MUCH<----------NO	2

Face-to-Face Interviews

The face-to-face interviews were conducted only with people who indicated an intention to use. In total, 205 people met this criterion. Respondents who were also willing to participate in the follow-up interview were contacted by ResearchNow and asked to provide contact information to schedule that interview. Of these people, researchers were able to identify, contact, schedule, and interview 44 people at the offices of the Texas A&M Transportation Institute in Austin, Texas. The interviews took place in June 2015. Questions concerned:

- Preference for being a driver or passenger on short-distance and long-distance trips.
- Feeling of safety when driving and feel safer or less safe in a self-driving vehicle.
- Concern for data privacy in self-driving cars.
- Preference to own a self-driving car as a personal vehicle or use as a shared vehicle.
- If the preference is to own, their willingness to pay and preference for vehicle size.
- If the preference is to share, their willingness to pay for access to a self-driving car-share vehicle.
- If self-driving vehicles were available today, their changes in household vehicles, VMT, residential location, commute mode, and mode or frequency of inter-city trips within Texas and outside of Texas.

Protocol

Q1. You indicated in the prior online survey that you would likely ride in a self-driving vehicle for everyday use. Can you tell me your reasons for that answer?

Q2. If you remember, we provided an opportunity to view a video of a self-driving vehicle. I want to show that to you again—prior to asking questions about how you would use such a vehicle.

Q3. Now imagine that you are riding by yourself in a self-driving vehicle on a trip to the grocery store. Describe what you think that experience would be like. PROBE to gather as much detail about the riding experience as possible.

Q4. Where would you sit and what would you focus on?

Q5. Now imagine that there are other people that you know in the vehicle. What would change, if anything, from what you just described?

Q6. I'm curious, when traveling in a conventional car in an urban area, do you prefer to be the driver or the passenger?

Driver (1)

Passenger (2)

Q7. Why is that? Please enter comments here.

Q8. What about when traveling in a conventional car for long-distance trips (50+ miles), do you prefer to be the driver or passenger?

Driver (1)

Passenger (2)

Q9. Why is that? Please enter comments here.

Q10. How safe do you feel in vehicles today when you are driving?

- Not at all safe (1)
- Somewhat safe (2)
- Moderately safe (3)
- Extremely safe (4)

Q11. Would you feel safer or less safe riding in a self-driving vehicle? Why is that?

- Safer (1)
- Less safe (2)
- About the same as now (3)

Q12. Why is that? Please enter comments here.

Q13. How would your feelings of safety while riding in a self-driving car differ between traveling in a urban area or on a freeway? Please enter comments here.

Q14. When you use internet-enabled technologies or services today, how concerned are you that your data is not kept private?

- Not at all concerned (1)
- Somewhat concerned (2)
- Moderately concerned (3)
- Extremely concerned (4)

Q15. Why do you feel that way? Please enter comments here.

Q16. How concerned are you that your data would not be kept private when using connected self-driving cars?

- Not at all concerned (1)
- Somewhat concerned (2)
- Moderately concerned (3)
- Extremely concerned (4)

Q17. Why do you say that? Please enter comments here.

Q18. Can you think of any potential problems or concerns you might have in using a self-driving vehicle that we've not yet discussed?

Q19. Now I'd like you to assume that self-driving vehicles were available for use today. Would you be more interested in owning one or just using one, like a Car2go or Uber taxi?
Owning as personal vehicle (1)
Using as shared vehicle (2)
Neither (3)

Q20. What issues would factor into your intention to own one?

Q21. How much EXTRA would you be willing to pay to own a self-driving vehicle? Say above the average price of a new vehicle, which was about $32K in 2014?

- Zero (1)
- A slight amount (2)
- A great amount (3)

Q22. Why is that? Please enter comments here.

Q23. Thinking about such a (self-driving) vehicle on a day-day-basis, who in your household would / could use it and for what?

Q24. IF VEHICLE OWNED NOW: Of the vehicles you own, what is the size of the vehicle that you drive most often?

- Compact (seats 4) (1)
- Mid-size (seats 4-5) (2)
- Full-size (seats 5-6) (3)
- Mini-van, Large SUV (4)

Q25. In terms of a self-driving vehicle, what size vehicle would you consider?

- Smaller (1)
- Same size (2)
- Larger (3)

Q26. IF DIFFERENT SIZE: Why would you change? Please enter comments here.

Q27. FOR THOSE WHO ANSWERED CAR SHARE: Why are you interested in using self-driving vehicles as a shared vehicle but not owning one?

Q28. How much EXTRA would you be willing to pay to access a self-driving car-share vehicle? Say above an average rate of $10 per hour for car-sharing?

- Zero (1)
- A slight amount (2)
- A great amount (3)

Q29. What is your reason for that? Please enter comments here.

Q30. You currently own "X number of" cars, how would that change if self-driving vehicles were available today?

Reduce (1)
No change (2)
Increase (3)

Q31. Why is that? Please enter comments here.

Q32. You now travel about XX miles in an average week. How would that change if self-driving vehicles were available today?

Decrease (1)
Stay the same (2)
Increase (3)

Q33. Why is that? Please enter comments here.

Q34. You now live [part of Austin], would where you live change if self-driving vehicles were available today?

- No change (1)
- Change (2)

Q35. What is your reasoning for that? Please enter comments here.

Q36. Would the way in which you commute to work change if self-driving vehicles were available today?

- No change (1)
- Change (2)

Q37. IF CHANGE: What would change? Please enter comments here.

Q38. How frequently do you make inter-city trips in Texas for work or leisure?

- Not at all (1)
- Occasionally (2)
- Frequently (3)
- All the time (4)

Q39. IF RELEVANT: How do you usually travel for your inter-city trips?

- Vehicle driver (1)
- Vehicle passenger (2)
- Air (3)
- Bus (4)
- Rail (5)

Q40. Would your mode of travel change for inter-city trips if self-driving vehicles were available today?

- No change (1)
- Change (2)

Q41. IF CHANGE: What would change? Please enter comments here.

Q42. How frequently do you travel outside of Texas?

- Not at all (1)
- Occasionally (2)
- Frequently (3)
- All the time (4)

Q43. IF RELEVANT: How do you usually travel outside of Texas?

- Vehicle driver (1)
- Vehicle passenger (2)
- Air (3)
- Bus (4)
- Rail (5)

Q44. Would your mode of travel change for out-of-Texas trips if self-driving vehicles were available today?

- No change (1)
- Change (2)

Q45. IF CHANGE: What would change? Please enter comments here.

Q46. Thank you for your time today. Is there anything else you want to tell me about how the availability of self-driving vehicles might impact your current travel behavior?

(Responses are given in the following list.)

At first I would probably ride more, it would be a fun new toy.
Feel more apt to travel and make it more comfortable. I would not get too tired or my feet and legs would not hurt because the driving part would not be there.
I do not drive in Austin; my husband usually drives everywhere I go. So I may go to more places if the car was driving.
I have wanted to take public transportation and it was never available. This would let me be more productive.
I think it is going to be something good. Baby boomers are coming around. Do not drive as much as I use to, this will make it easier to make more trips.
I think it is safer so people can be more focus and it would prevent accidents. not have to worry about concentration
I think my behavior would stay the same but it should improve safety and I would do it for that reason.
I would be more interested in moving within the city because I would have access to self-driving vehicles. Most things like this are only available within the city not in the surrounding areas. I would like to see them available in the surrounding areas.
I would definitely want to try one before I considered buying or using one. How you feel in the car would seal the deal or make you nervous. Do I feel safe? One of the big deciding factor. Be interested in its reaction time in an urban environment. Want to know that it would react better than you as human could. On other hand, if it is highly sensitive jerking all the time then hard to be a passenger in one.
I would feel less stress on a daily basis and many more people had them I would be less worried about accident, more work done and not having to focus on driving.
I'd have to experience a bit to get confidence -- but if i had it then i could be ready to travel around Texas more. Marble falls, Wimberley, etc.

I'm excited for them. It is going to change the way we function in our lives. It takes the human error. It will make us more productive and safer
It would be awesome and I want one.
It would enhance the experience. I grasp and embrace technology because I believe it really will be safer and I think it is just the future.
More excited to use the car. I would chose my car instead of a friends
My normal commute would improve. Less change for human error. Less accidents. Everything would be smoother.
Only concern is when everyone has a self-driving vehicles, it would increase vehicles on roadway. Would need a class to teach the older driving how to handle one.
Please feel free to call me to follow up with any questions or studies on this subject.
The speed and pace of how the cars. Would it be the pace that I am used to driving
Very interested in that type of transportation. Would love to be in a program to test drive them. Believe that is the future.
We might take once a year more often go a trip somewhere. Because we wouldn't be thinking/ worrying about the driving. It would be possible to say take the trip overnight - we're going to sleep - motel on wheels. a time saver in that regard/
When is it available and when can I check it out. I'm very curious
Would be wonderful to help take our son to doctor who has bi-polar. We have to schedule him appointments out of town because he does not like a lot of traffic. It would be wonderful to be able to take him where we needed and not have to drive.
Would like to know the legal driving age, and if it can operate with not human in the vehicle. What about if I have had a couple of drinks, if is legal to just let the vehicle do the driving. A little nervous at first until I got to trust the vehicle.
Would prioritize things; there is a difference of having you own vehicle and doing what you want when you want. However, you are subject to a lot of other costs i.e.: insurance, maintenance, etc.

Appendix B: Prior Studies

This study relied on two strands of prior research:

- The literature on how to examine acceptance and adoption of new technologies that are not yet on the market.
- The burgeoning knowledge base on acceptance and adoption of AVs and the potential impact on travel behavior.

Vehicle Technology Acceptance and Use

The last decade has witnessed an explosion in the availability of new vehicle technology, a general term referring to the application of mechanical, electronic, information, and communication systems and new materials in the driving environment. Some technology is built into the vehicle by manufacturers, some has been added in aftermarket products, some has been brought into the vehicle by drivers (e.g., mobile devices); and some has been applied to roadway infrastructure to inform drivers (e.g., variable message signs) and to support driver safety (e.g., speed cameras). Like the information technology that was introduced into homes and businesses in the 1980s, new vehicle technologies will not benefit users unless the technologies are accepted and used. In the special case of self-driving vehicles, the potential societal benefits (e.g., enhanced safety, reduced congestion, and improved air quality) of these vehicles will not be achieved unless they are accepted and used by a critical mass of drivers. Research on this topic can gain much value from the rich history of predecessor research pertaining to acceptance and adoption of information technology.

In the information technology realm, acceptance has been defined as the "demonstrable willingness within a user group to employ information technology for the tasks it is designed to support" (*10*). Frequently used frameworks to define and measure the acceptability of information technology are the Theory of Planned Behavior (*11*) and the Technology Acceptance Model (*12*, *13*). Venkatesh et al. (*6*) were successful in synthesizing the different underlying concepts in these and six other frameworks to form a Unified Theory of Acceptance and Use of Technology (UTAUT). Constructs were combined to form five UTAUT variables:

- Performance expectancy—the degree to which an individual believes that using the system would help him or her to attain gains in job performance.
- Effort expectancy—the degree of convenience with the use of the system.
- Social influence—the importance of other people's beliefs when an individual uses the system.
- Facilitating conditions—how an individual believes that an organizational and technical infrastructure exists to support use of the system.
- Behavioral intention to use a system.

UTAUT was validated in a longitudinal evaluation as determining usage intention and behavior. Osswald et al. (*14*) further adapted the UTAUT model to make it applicable to the car context. Their Car Technology Acceptance Model added the following variables based on automotive research literature:

- Perceived safety while driving.
- Anxiety in the car context.
- Attitudes toward using the technology.

Anxiety and attitudes were dropped as non-significant in the UTAUT model.

In the domain of vehicle technology, acceptance has been defined as the "degree to which an individual incorporates the system in his/her driving, or, if the system is not available, intends to use it" (*10*). With self-driving vehicles, the intent to use is an important concept because the technology is not yet on the market. Intent to use is based on the level of acceptance. It is not until a product becomes tangible and drivers have an opportunity to experience it that they can form judgments and provide reliable and valid responses to questions pertaining to *actual* use.

Data Collection on Acceptance and Use of Automated Vehicles

Data on acceptance and use have been traditionally collected via qualitative methods (e.g., focus groups and interviews) and surveys. Qualitative methods are used for vehicle technologies in the concept stage, whereas surveys have been used when there is a partial or fully functional prototype (*15*). Various researchers have previously conducted surveys on automated driving systems; however, there was a dearth of focus group research available for review.

None of the surveys available for review in this study followed a theoretical or conceptual model of acceptance and use, and all were one-off, customized surveys by academic or industry researchers. The research spans a variety of methodological approaches, data sources, and variables, which resulted in conflicting findings, making it difficult to compare results.

In 2014, Schoettle and Sivak (*16*) of the University of Michigan Transportation Research Institute (UMTRI) investigated public opinion about autonomous vehicles in the United States, the United Kingdom, and Australia using SurveyMonkey software. SurveyMonkey's Audience tool was used to target and recruit individuals 18 years old and older from its respondent databases in the three countries. Researchers used NHTSA's definition of levels of automation in textual form as the basis for the questions asked. Results indicated that most respondents (ranging from 63 percent to 68 percent) were interested in having completely self-driving vehicle technology, but the majority of respondents said they would not be willing to pay extra for this technology. U.S. respondents expressed greater concern than those from the United Kingdom or Australia regarding data privacy, interaction with non-self-driving vehicles, learning to use the vehicles, vehicle performance in poor weather, and self-driving vehicles not driving as well as humans. Younger respondents, regardless of country, were more interested in having self-driving

technology and more likely to expect societal benefits in terms of less traffic congestion, shorter travel times, and lower insurance rates.

Kyriakidis et al. (*17*) of the Delft University of Technology surveyed people in 109 countries in 2014 using a crowdsourced software system, CrowdFlower (www.crowdflower.com). This survey used definitions of manual driving, automated driving, highly automated driving, and fully automated driving developed by the Germany Federal Highway Research Institute. Respondents indicated that fully automated driving would be easier than manual, whereas partially automated driving was perceived as more difficult. Concerns focused on software hacking and misuse, legal issues, and safety. On average, respondents were willing to pay more for fully automated driving. Willingness to pay was associated with both higher income and vehicle kilometers/miles of travel. Neither age nor gender was a significant factor.

In 2012, researchers from the Center for Transportation Research at the University of Texas at Austin conducted an online survey of 675 respondents in six metropolitan cities of South Korea to investigate consumer preferences and willingness to pay for advanced technology options (*18*). The stated-choice approach was applied to understand consumer preferences for alternative fuel choices (e.g., electric hybrid, natural gas, and hydrogen) and willingness to pay for smart features (e.g., autonomous driving, connected systems, wireless Internet and communication, and real-time traveler information). The research found that consumers had the greatest willingness to pay for connectivity and wireless Internet and the least for lane keeping.

On the industry side, Continental AG conducted online surveys with car users in four countries (i.e., Germany, China, Japan, and the United States) in 2013 to examine attitudes toward driving, advance driver assistance systems, and automated driving (*19*). In all countries but the United States, the majority of respondents thought automated driving was a useful advancement (Germany had 53 percent, China had 79 percent, Japan had 61 percent, and the United States had 41 percent). U.S. respondents were also more likely to say that automated driving scares them. Across the countries, respondents preferred the use of automated driving on long freeway journeys (67 percent) and in traffic jams (52 percent), and less on rural roads (36 percent) and in city traffic (34 percent). In a segmentation scheme that was developed, U.S. respondents were most likely to be characterized as "wait and see" (43 percent), rather than "skeptics" (37 percent) or "fans" (20 percent).

Deloitte Consulting conducted a 2014 Global Automotive Consumer Study in 19 countries (*20*). The firm did not release methodological information. In the aggregate, 31 percent of respondents indicated that they would find full self-driving desirable. Younger people (i.e., Gen Y) were more favorable about full self-driving (47 percent). Gen Y consumers ranked vehicles that do not crash and vehicles that use alternative fuels as the technologies from which they expect the greatest benefits.

With a focus on the United States, researchers at the University of California, Berkeley in 2013 examined public perceptions of self-driving cars (*21*). The researchers felt that the main obstacle to collecting valid data was the public's lack of knowledge about self-driving cars, so they

targeted science museum visitors in Berkeley, California. The survey was advertised at the ticket admissions desk and administered in a classroom group setting in the museum. A10-minute informational video was shown to respondents to ensure all had similar information. The sample totaled 107 people, of which 41 percent said that they would retrofit an existing car with self-driving technology and 42 percent said they would look for self-driving technology in their next vehicle purchase. Income level and the relationship of people to technology were correlated to positive responses regarding adoption of self-driving technology. Respondents' willingness to use self-driving taxis was not high. The most attractive features of self-driving cars were safety, amenities like multitasking, and convenience. Respondents were most concerned with liability, costs, and control.

In a 2014 survey, the market research firm J.D. Power found that nearly one-fourth (24 percent) of vehicle owners in the United States were interested in paying to have autonomous driving mode ($3,000) in their next vehicle. This was up from 21 percent in 2013 and 20 percent in 2012 (*22*). The J.D. Power survey is an annual cross-sectional survey of vehicle owners and assesses interest and purchase intent for 61 emerging automotive technologies both before and after the market price is known. The technologies that garnered the most consumer interest were wireless connectivity systems, which create a communication link between electronic devices and the vehicle (83 percent); and a device/application link, which allows viewing and controlling electronic devices and apps though factory-installed equipment (78 percent).

While the surveys examined acceptance and use, none looked at the question of potential impact on travel demand. Several studies applied modeling techniques to existing datasets to examine such questions. These studies concluded that vehicle ownership would decrease, VMT would increase, and transit mode share would decrease. While such studies provide direction in terms of potential impacts, they are limited in deepening our understanding of the determinants of acceptability, adoption, and use of self-driving vehicles.

Schoettle and Sivak (*7*) of UMTRI analyzed 2009 National Household Travel Survey (NHTS) data files to examine the impact of self-driving vehicles on household vehicle demand and use. They investigated the potential for reduced vehicle ownership within households due to new opportunities for sharing of completely self-driving vehicles that would employ a return-to-home mode. They found that 84 percent of households had no trips that overlapped or conflicted, which would permit sharing of self-driving vehicles within the household. They concluded that such sharing would result in a 43 percent reduction in the average number of vehicles per household (from the current 2.1 vehicles per household to 1.2 vehicles per household).

Harper et al. (*23*) estimated the impact of a fully automated vehicle environment on total VMT due to increased mobility from non-drivers, elderly, and people with travel-restrictive medical conditions. Using 2009 NHTS data, they first computed and analyzed average annual VMT for drivers, non-drivers, the elderly, and those with and without travel-restrictive medical conditions. Then, they computed three demand wedges:

- In demand wedge one, they assumed that non-drivers would travel as much as drivers within each age group and gender. The total increase in annual VMT was 148 billion miles (a 6 percent increase in total VMT).
- In demand wedge two, they assumed that the driving elderly without medical conditions would travel as much as the general population within each gender. The total increase in annual VMT was about 55 billion miles.
- In demand wedge three, they assumed that drivers with medical conditions would travel as much as drivers without them within each age group and gender. The total increase in annual VMT was 57 billion miles.

If all three demand wedges were combined and took place simultaneously, the VMT would increase by about 12 percent. The paper notes that the effect of vehicle automation on the travel characteristics of the elderly and those with a travel-restrictive medical condition will depend on the cost of AV technology and their willingness to adopt it.

To help decision makers understand the impact of AV technology on regional plans, Childress et al. (*24*) used the Seattle region's activity-based model to test a range of travel behavior impacts. Four scenarios were considered:

1. AVs use existing facilities more efficiently, and capacity increases by 30 percent.
2. Important trips are in AVs, capacity increases, and the value of time decreases by 65 percent for the high-value-of-time household trips.
3. All cars are self-driving, none are shared, capacity increases, the value of time decreases, and parking costs decrease by 50 percent.
4. All autos are automated, all costs of auto use are passed on to the user, and per-mile auto costs increase to $1.65.

Under these scenarios, VMT increases by 4 percent in scenario 1, increases by 5 percent in scenario 2, increases by 20 percent in scenario 3, and decreases by 35 percent in scenario 4. There is little difference in mode shares from the base year except for scenario 4, in which the single-occupancy vehicles share decreases from 44 percent to 29 percent, transit increases from 3 percent to 6 percent, and walking increases from 9 percent to 13 percent.

Levin and Boyles (*25*) developed a model to analyze the impact of AV availability on AM peak transit demand. The model simulates the effect of vehicles that drop off passengers at their destination and return to pick up passengers at the end of the day—enabling an assessment of the cost impacts of avoiding parking fees but incurring additional costs from travel time, monetary fees, and fuel. An accompanying assumption was that AV use increases road capacity and reduces travel time. A multi-class four-step planning model was tested on the Austin downtown network including its bus routes. Results indicated that parking cost was a main incentive for transit and that avoidance of parking costs through AV round trips resulted in both an increase in AV round trips relative to one-way and park trips and a decrease in transit use. Increases in travel times were offset by the road capacity increases of AV use.

Fagnant et al. (*26*) examined the potential impact of a shared autonomous (or fully automated) vehicle (SAV) fleet—combining features of short-term on-demand rentals with self-driving capabilities—on trip making in Austin. Simulating a sample of trips from the region's planning model to generate demand, researchers found that each SAV was able to replace around nine conventional vehicles within the downtown area while still maintaining a reasonable level of service. Additionally, approximately 8 percent more VMT could be generated due to SAVs operating in an empty mode to the next traveler or relocating itself to a more favorable location to find potential passengers.

Appendix C: Modeling AV Impact Using the CAMPO Model

Assuming that the travel time will be less onerous with the introduction of automation, different scenarios were tested in the CAMPO model by reducing the negative impact of the time spent in the vehicle on travelers. This was achieved by reducing the magnitude of the coefficient of in-vehicle travel time (CIVT) variable in the utility expression of the mode choice model of the 2010 CAMPO travel-demand model. The utility expression for each available mode is specified as a linear function, which incorporates a range of variables, such as travel time (e.g., in-vehicle travel time and out-of-vehicle travel time), travel cost (e.g., transit fare and parking cost), and locational measures (e.g., employment and population density). While keeping the coefficient of all other variables identified in the utility function the same as CAMPO model estimates, the coefficient of in-vehicle travel time variable was changed for the current purpose of testing. As expected, in the CAMPO model, the estimated coefficient on the travel time variable is negative, indicating that the utility of a mode decreases as the travel time associated with that mode increases. Therefore, when the value of CIVT is decreased, while the probability that the mode will be chosen still decreases (due to the negative sign of the CIVT), the reduction leads to a less pronounced negative effect under these scenarios. In other words, the greater the magnitude of reduction in the CIVT in the utility function of a mode, the less onerous in-vehicle travel time will be for that mode.

Given that no specific assumption can be made on the magnitude of the reduction needed, two scenarios were developed at two quartiles: 25 percent reduction in CIVT and 75 percent reduction in CIVT, while keeping all other parameters the same. These scenarios are developed as general impacts and should be evaluated with caution. Travel-demand models are calibrated and validated based on observed data or revealed preferences. Given AVs are not yet traveling on the transportation system, the model results might not accurately represent the changes under AV scenarios since no observed data are yet available for this emerging technology. Estimating the congestion impacts of AVs requires a complex set of structural changes in the CAMPO model. Therefore, the results provided here are meant to prompt discussion on broad impacts. This section briefly summarizes the model scenario results.

Changes in VMT

There was a slight increase in total daily (or 24-hour) VMT with a reduction in the disutility of travel (or CIVT) (see Figure 5). The total daily VMT increases by about 0.14 percent when the CIVT reduction is set to 25 percent and by about 0.03 percent when the CIVT reduction is set to 75 percent.

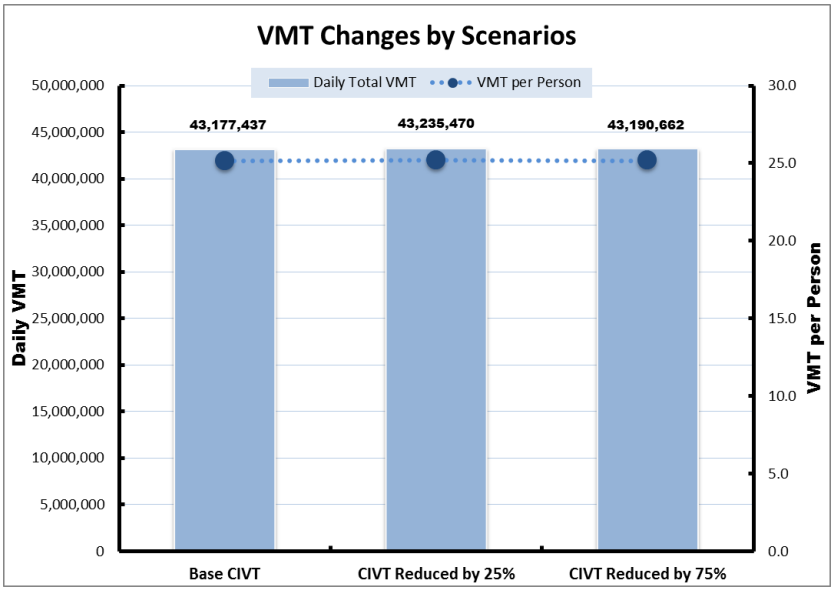


Figure 5. VMT Changes by Scenario.

Changes in Mode Use

These changes make individuals both more likely to use autos and less likely to use transit (see Figure 6 and Figure 7). The total number of transit trips decreased from 107,595 trips to 77,662 trips with a 25 percent reduction in CIVT, and to 80,809 trips with a 75 percent reduction in CIVT (about a 0.6 percent decrease in overall transit share).

The decreasing trend in the total number of transit trips was particularly pronounced for local bus mode compared to other transit modes, including express bus, commuting bus, and rail (see Figure 6):

- A 25 percent reduction in CIVT resulted in a 75 percent decrease in the total number of person trips made by a local bus. The trips decreased from 61,738 person trips to 15,645 person trips.
- A 75 percent reduction in CIVT resulted in a 72 percent decrease in the total number of person trips made by a local bus. The trips decreased from 61,738 person trips to 16,857 person trips.

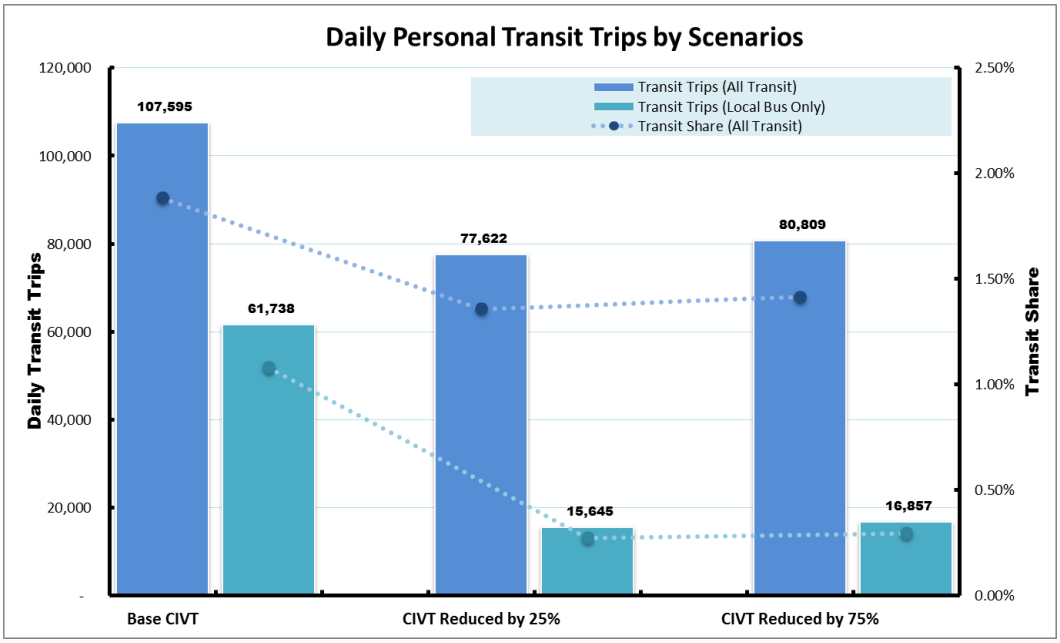


Figure 6. Daily Transit Person Trips by Scenario.

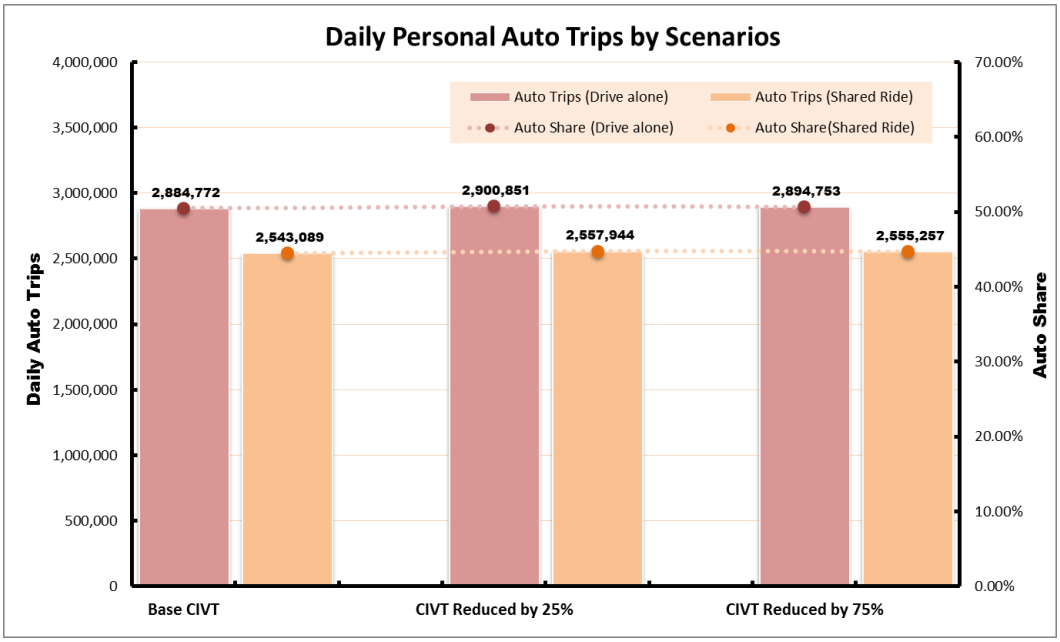


Figure 7. Daily Auto Person Trips by Scenario.

With a 25 percent reduction in CIVT, the total number of auto person trips increased from 5,427,861 trips to 5,458,795 trips. With a 75 percent reduction in CIVT (about a 0.5 percent increase in overall auto share), the total number of auto person trips increased to 5,450,010 trips. The increasing trend in total number of auto person trips was observed across all categories of auto trips but with slightly different rates (see Figure 7):

- 25 percent reduction in CIVT:
  - The drive-alone mode increased by around 0.56 percent.
  - The shared ride with two people increased by around 0.67 percent.
  - The shared ride with three people or more increased by around 0.38 percent.
- 75 percent reduction in CIVT:
  - The drive-alone mode increased by around 0.35 percent.
  - The shared ride with two people increased by around 0.58 percent.
  - The shared ride with three people or more increased by around 0.25 percent.

With respect to the auto mode, the reduction in CIVT was most influential for the increase in home-based work and home-based education trips.

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