Final Project Report

Interaction of Familiarity, Safety Perceptions, and Willingness to Use Autonomous Vehicles in A Structural Equation Modeling Framework

Prepared for **Teaching Old Models New Tricks (TOMNET) Transportation Center**

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16. Abstract

Autonomous Vehicles (AVs) are an important technology in the future of transportation systems. While attitudes and perceptions towards AV have been studied in the past, the role of different levels of AV familiarity in shaping relative attitudes and expected adoption has been underexplored. Using the TOMNET Transformative Technologies in Transportation (T4) Survey data that serves as the base for this study, 47 percent were somewhat or very familiar with AVs while 36 percent had heard but did not know much about them and 15 percent had never heard of AVs before. Based on these survey results, the level of familiarity increases among higher educated people, ridehailing systems users, people with variety-seeking attitudes, male, non-Hispanic, and higher-income people. The goal of this project is to study the multivariate relationships between different levels of AV familiarity, positive perceptions toward AV, and potential adoption of AV in the future, accounting for environmental friendliness, tech savviness, and also general socioeconomic attributes. To accomplish that, a structural equation model was estimated. The results of this study will help policymakers to understand better the effects of familiarity and perceptions on willingness to use AVs, allowing for more informed decisions regarding public education strategies and investments to ensure the smooth adoption of an automated future.

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EXECUTIVE SUMMARY

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INTRODUCTION

Autonomous vehicles (AVs) are the most prominent emerging technology in the future of transportation. Sooner or later, people will sit in AVs without the need to drive; they can send their vehicles on pick-up and drop-off trips on their own, or even give rides to children and adults who cannot drive. As soon as it became apparent that fully automated vehicles could be developed, researchers started studying public opinions in various domains of the technology. Gastonia and Gkritza [1] performed a comprehensive review of the topic and identified that more than half of the reviewed studies on AVs focused on capturing the behavioral characteristics and perceptions of individuals. Howard and Dai [2] identified that the highest valued benefits of automated mobility are increased road safety, self-parking convenience, and the ability to multitask, while the largest concerns or disbenefits were liability and affordability.

Several surveys have been conducted to study the awareness of and familiarity with AVs. Schoettle and Sivak [3] reported that 66 percent of respondents were aware of AVs before their survey. Pettigrew et al. [4] suggest a general acceptance of automated mobility and highlighted that benefits of AVs had mostly a cognitive nature, while concerns, when present, were mostly associated with an emotional tone. Nielsen and Haustein [5] identified that the most enthusiastic supporters of AVs are usually highly educated young men, who live in large urban areas. Saeed et al. [6] identified that those familiar with car-sharing services were more likely to use for-hire AVs. In China, Wu et al. [7] observed that familiarity and perceived benefits have positive effects on the behavioral intention of survey respondents to adopt Autonomous, Connected, and Electric Vehicles (ACEVs). In Sweden, Chee et al. [8] identified that familiarity with automated driving technology is an important factor affecting willingness to pay for AV service. Results supported the idea that when people become more scientifically knowledgeable and familiar with a certain technology, they are more likely to endorse that technology [9].

Among all the studied domains of public perceptions around vehicle automation, the perceived safety of the technology in the form of each of the benefits of eliminating human error and the potential concern of technology failure raised the greatest attention. The perception of how safe an AV is will potentially impact how citizens plan to adopt the technology when available. Bansal and Kockelman [10] reported that reduction in vehicular crashes was identified as the best benefit of AVs, while technology failure was identified as the largest concern. Hulse et al. [11] found AVs to be perceived as relatively low risk and, despite concerns, there was little opposition to automated mobility. Hulse et al. [11] also identified that AVs were perceived as riskier by passengers and by women, and perceived as less risky by pedestrians, the young, and male respondents. Howard and Dai [2] also highlight that men are more concerned with liability in comparison to women, and low-income individuals were more concerned with safety.

Although one very important and valuable goal of automation technology is to improve safety, concerns about equipment failure have increased in recent years at least in the US. Bansal and Kockelman's [10] study in Texas showed 50 percent of respondents being concerned about the safety of the automation technology. However, the same survey in 2018 showed 61 percent of respondents being concerned. Similarly, Nazari et al. [12] reported 67 percent being concerned about technology failure in the State of Washington. The trend of increasing concern is shown further by the JD Power survey [13], which reported 71 percent of people being concerned and, conducted in the same year, the T4 survey [14], on which this study is based, reported 68 percent to be concerned. One potential reason for this trend of increasing level of concern toward the technology could be a result of the multiple AV accidents that have happened during recent years including the Uber accident in Tempe, AZ [15].

In addition to familiarity and safety perceptions, previous studies have also measured public opinion about various ways of expected adoption of automation technology. Lavieri et al. [16] identified that younger, tech-savvy, and educated urban residents are more likely to be early adopters. Haboucha et al. [17] identified three latent factors when modeling vehicle choice between regular private cars, privately owned AVs, and shared AVs, namely preferences towards driving, environmental concerns, and pro-AV attitudes. Those who expressed greater concern for the environment also showed a stronger intention to use shared vehicles; young and educated individuals who spend more time inside vehicles reported a stronger intent to be early adopters of AV technology [17]. Nielsen and Haustein [5] identified that those who are enthusiastic about AVs (typically young, educated men) are more likely to use them in all forms. Nazari et al. [12] identified that while safety concerns can hinder interest in AVs, interest in mobility-on-demand automated services and green travel patterns can promote technology adoption. Panagiotopoulos and Dimitrakopoulos [18] identified the perceived usefulness of AVs, perceived ease of use, trust, and social influence as the strongest predictors of the intended adoption of automated mobility. Gkartzonikas and Gkritza [1] also identified nine concepts that could potentially impact one's intention to ride in an AV. They are the level of awareness of the technology; consumer innovativeness; safety; the trust of strangers; environmental concerns; relative advantage, compatibility, and complexity in comparison to regular vehicles; external social pressures; whether a person considers him/herself capable of doing a specific task; the individual's need for complex sensations; and his/her willingness to take risks. Kim et al. [19] found that important predictors of behavior in an all-AV era are the perceived advantages and benefits of AVs, and respondents' concerns with the negative impacts on the overuse of automated technology.

The level of public familiarity, trust, and various perceptions will impact AV adoption behaviors when AVs become available in the future. It is very important to understand these relationships today to shape the adoption and adaptation pathways of the future effectively and help the private and public sectors plan better for the successful and safe launching of AV technology in the real world. While familiarity with AVs has been identified to be positively correlated with willingness to engage with AVs [20, 3], the complex relationships between awareness of the technology, perceptions towards automated mobility, and expected future engagement with it are still underexplored. Liu et al. [21] reported that most studies did not identify the previous familiarity with self-driving technology as a strong predictor of willingness to pay for them [22]. Liu et al. [21], however, acknowledged the familiarity hypothesis – where support for emerging technologies grows as its awareness expands – and therefore suggest that the link between familiarity and willingness to adopt might change in the future. To what extent familiarity matters in shaping favorable AV perceptions and adoption patterns are the research question of this study. The statistically significant and unbiased response to this question that controls the contributions of other factors will determine to what extent we should invest in resources to educate people and at what level we should do that.

The TOMNET Transformative Technologies in Transportation (T4) Survey [14] focused on collecting data about attitudes, perceptions, and choices towards new mobility services, such as ridehailing services and AVs to help shape the policy and planning efforts of the future transportation system. The full deployment phase of the T4 survey collected data in Phoenix, Atlanta, Tampa, and Austin during late 2019 before the pandemic. The full deployment was conducted only in an online format mainly based on random address-based samples, and a total of 3,465 responses were obtained.

Two features of the TOMNET T4 survey make it rather distinct and complementary to the previous related studies. The first feature is the inclusion of a rich battery of attitudinal statements (general and transport-related) that enable this study to strongly control for latent attitudinal constructs in addition to socioeconomic variables. The other feature is the large sample size across four southern cities compared that enable us to hear voices from auto-oriented places. Using such a rich T4 Survey dataset, this study concentrates on examining the relationships between level of familiarity, perceptions toward AVs, and the willingness to use AVs in the future, while also controlling for socioeconomic and attitudinal factors. The approach to the analysis of the data is to use a structural equation model, estimated from the T4 Survey data.

DATA

The full deployment phase of the T4 survey collected data during the Summer and Fall of 2019. The full deployment survey instrument was divided into six sections:

- Attitudes and Preferences,
- Household Vehicles and Residential Preferences,
- Current Travel Patterns,
- Mobility on Demand,
- Thoughts on AVs, and
- Background Information.

The survey collected data in Atlanta, Tampa, Austin, and Maricopa County (Arizona). More information about data cleaning, income imputation, and other data processing can be found at [14]. To investigate the relationship between AV adoption and familiarity with AV technology, records with missing data on key variables of this study are not included. Thus, after cleaning, the sample used in this study consists of 2,870 records.

After weighting, the sample fairly replicates the true population in all the 26 counties included in the survey deployment. To understand better how the weighted sample performs, the weighted distributions are compared to the proportions observed on the 5-year estimates from the 2017 American Community Survey, derived from the IPUMS data [23].

Table 1 compares the weighted sample distribution with the true population of the counties sampled in the four Southern Cities investigated in this research project. Age, gender, Hispanic status, tenure, household size, and household income are well represented in the weighted sample. As with any weighting scheme, the weights improve the overall representativeness of the sample. However, the weighted data do not replicate exactly the population distributions regarding all control variables. For the full deployment of the T4 Survey, this means the weighted sample slightly underrepresents individuals without post-secondary education and households with children.

To understand better the effect of AV familiarity on safety perceptions towards AVs, those who reported having taken a ride in an AV, to be very familiar or somewhat familiar with AVs were grouped as being familiar with AVs, representing 48 percent of the weighted sample. On the other hand, 52 percent who had heard of AVs but did not know much about them, and those who had never heard of AVs before taking the survey were labeled not familiar with AVs. Safety perception can be defined based on the agreement with the statement "I am concerned about the potential failure of AV sensors, equipment, technology, or programs". Those who somewhat or strongly agreed with the statement were concerned with AV technology (68.3 percent) and those who somewhat or strongly disagreed with the statement were not concerned (14.4 percent). The remainder were grouped as being neutral to AV safety. While 66 percent of those who were not familiar with AV technology at the time of the survey were concerned with potential failure, 70 percent of those who were familiar with it felt the same. This suggests that negative safety perception was not largely improved by familiarity with the technology (Figure 1). However, positive safety perception increased from 11 percent among unfamiliar respondents to 18 percent among familiar respondents, and the percent of neutral responses decreased accordingly.

Table 1 Description of the Data Collected in the T4 Survey, Full Deployment Sample (Weighted)

Person Characteristics	Sample (N=2,870)	Census – 26 counties	Household Characteristics	Sample (N=2,870)	Census – 26 counties
Age			*Household Size*		
18-30 years	23.5%	23.5%	1	23.8%	30.8%
31-40 years	17.3%	18.2%	2	36.3%	32.3%
41-50 years	17.3%	18.1%	3	15.0%	14.9%
51-60 years	16.3%	16.7%	4	14.7%	12.5%
61-70 years	14.9%	12.8%	5 or more	9.7%	9.5%
71+ years	10.6%	10.6%	*Vehicles available to the household*		
Gender			0	3.6%	5.9%
Male	49.3%	48.3%	1	34.3%	35.0%
Female	50.6%	51.7%	2	43.1%	37.5%
Gender not available	0.1%	-	3	11.7%	12.5%
Employment Status			4 or more	7.3%	9.1%
Worker (part- or full-time)	56.1%	62.1%	*Household Income*		
Both worker and student	8.5%		Less than $25,000	13.6%	17.7%
Student (part- or full-time)	9.0%	37.9%	$25,000 to $49,999	21.1%	22.6%
Neither worker nor student	26.4%		$50,000 to $99,999	33.3%	30.1%
Education Attained			$100,000 to $149,999	19.6%	13.6%
Some grade/high school	5.5%	12.1%	$150,000 to $249,999	8.6%	8.0%
Completed high school or GED	22.7%	25.3%	$250,000 or more	3.7%	8.0%
Some college or tech. school	33.7%	31.4%	*Tenure Status*		
Bachelor's degree(s) or some graduate school	24.5%	22.2%	Rent	29.7%	36.7%
Completed graduate degree(s)	13.5%	9.0%	Own	62.5%	59.2%
Hispanic Origin			Provided by somebody else	6.7%	4.1%
Not Hispanic	81.3%	82.1%	Other	1.1%	
Hispanic	16.3%	17.9%	Tenure not available	0.4%	-
Hispanic origin not available	2.4%		*Presence of Children*		
			Not present	78.9%	68.7%
			Present	21.1%	31.3%

Figure 2 shows how willingness to ride in an AV varied for groups based on their familiarity with and perceived safety of the technology. Comparing the right three bars to the left three bars indicates that familiarity consistently increases willingness to ride in AVs with various levels of concern about the technology. In both the familiar and the not familiar groups, those who were concerned with potential technology failure were less willing to ride in an AV compared to those who were not concerned. Interestingly, those who reported neutral perceptions of AV safety were also more likely to be neutral when reporting willingness to ride in an AV, especially among non-familiar individuals. Exploring the complex relationship between familiarity, safety perceptions, and willingness to adopt AVs is very critical in shaping ongoing planning efforts for sustainable, safe, equitable, and efficient AV adoption. This study will use Structural Equation Modeling to simultaneously study this relationship accounting for socioeconomic and general attitudes.

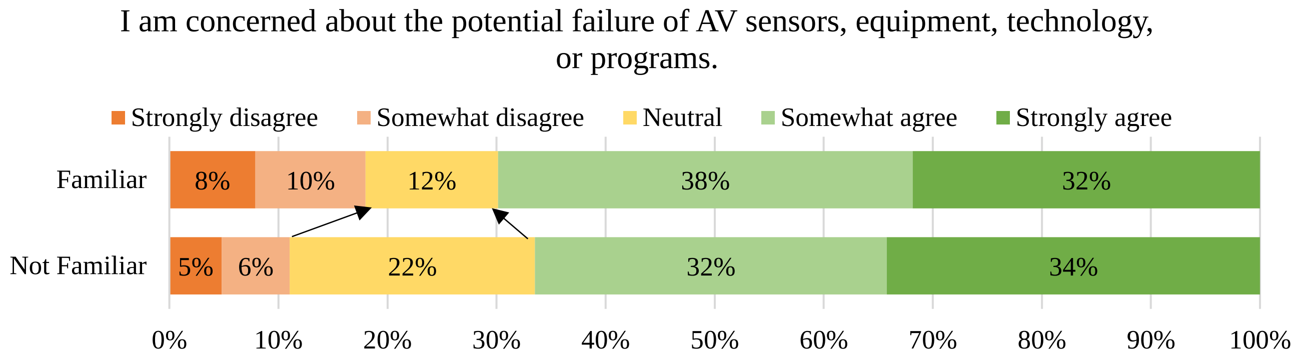

Figure 1 Relationship between Concern about AVs and Familiarity with the Technology (Weighted)

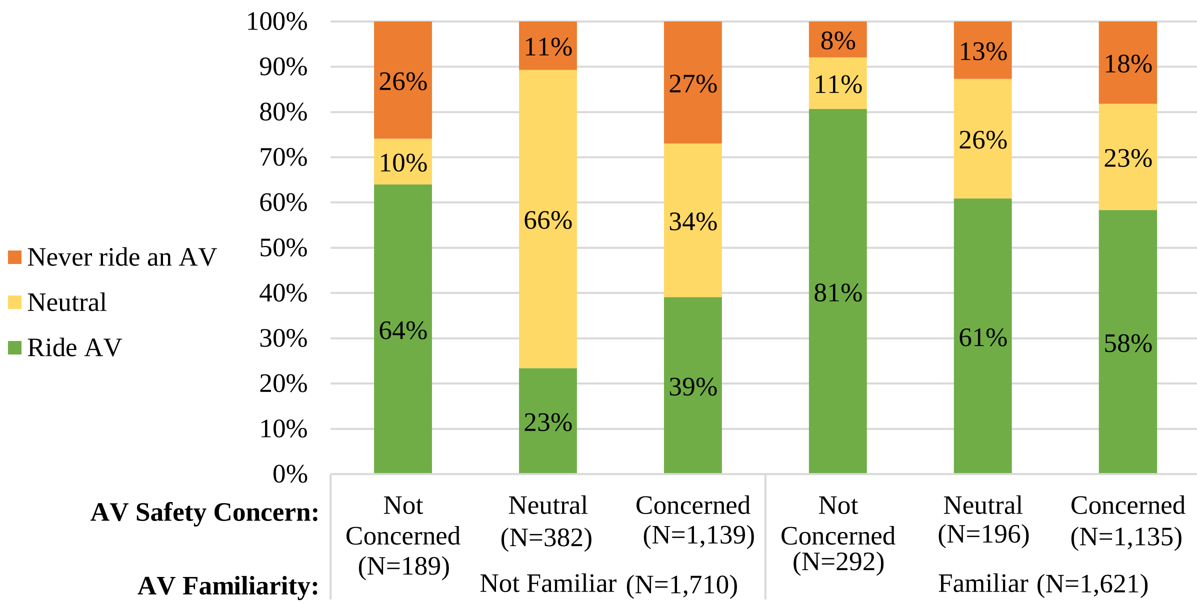

Figure 2 Willingness to Ride in AVs, by Familiarity and Perceived Safety of the Technology (Weighted)

METHODS

Travel behavior research has previously used Structural Equation Modeling (SEM) for analyzing attitudinal data [24], and SEM is a recognized modeling tool to investigate the effects of attitudes on travel behavior [25, 26, 27]. For example, Asgari and Jin [28] used a similar Structural Equation Models framework to investigate willingness to pay for AVs, and AV adoption, accounting for the joy of driving, choice reasoning, trust issues, and tech savviness. Figure 3 shows the proposed methodology framework for this study. Therefore, to identify attitudinal constructs measured through indirect indicators, as well as to understand the relationship between the target endogenous variables, the latent attitudinal factors, and other exogenous variables, SEM was the chosen methodology. The main variables under study are AV Favorable Perception and AV Adoption, and an important aspect of this model framework is the consideration of the attitudinal constructs including Tech-Savviness and Environmental Friendliness as endogenous.

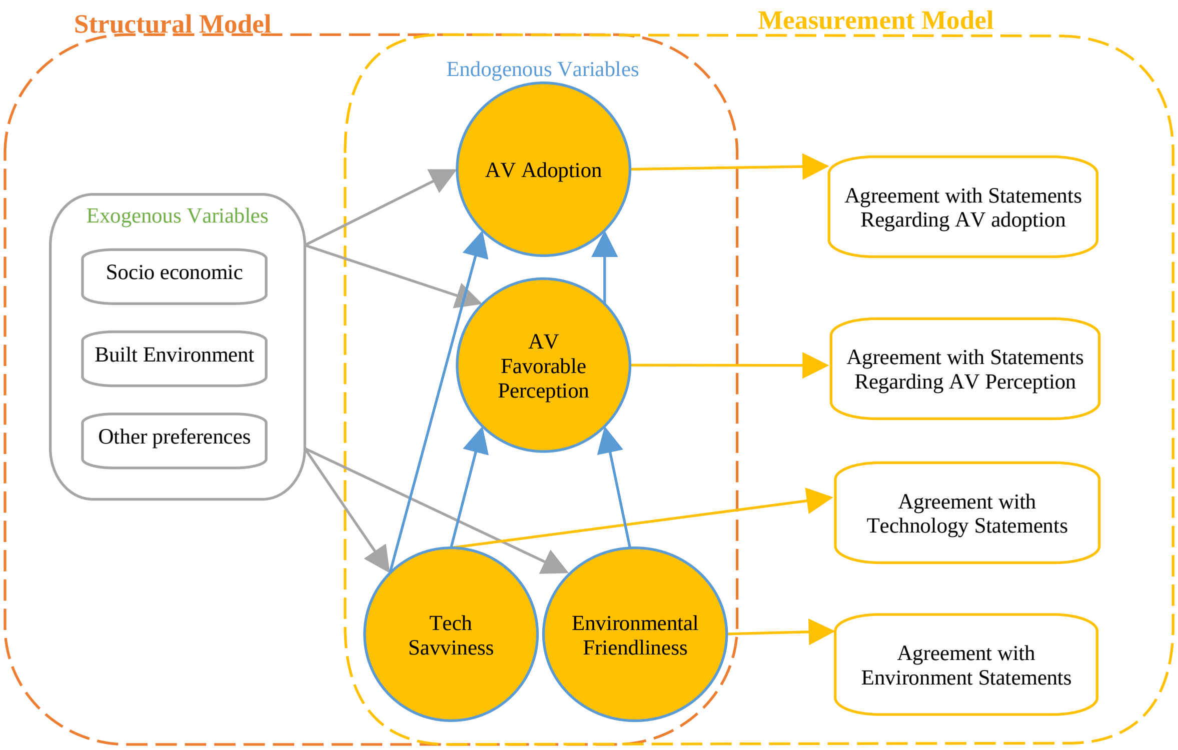

Figure 3 Proposed Modeling Framework for the Investigation of the Relationship between AVs Perceptions and Willingness to Adopt the Technology

The first portion of the structural equation model involves a measurement model, that measures the relationship between attitudinal indicators (asked in the survey by the rating of agreement with given statements, answered on a 5-point Likert scale) and unobserved latent constructs (AV Adoption, AV Favorable Perception, Tech-Savviness, and Environmental Friendliness). The measurement models to estimate factors for latent attitudinal constructs were defined based on the literature to date and survey design elements.

Table 2 shows the references that support the choice of the statements used on the hypothesized measurement model. The Attitudes and Travel Database [29] was used to assist in identifying the resources related to each of the factors in this analysis. In addition to that procedure, an exploration of the measurement instrument was performed to ensure its good fit to the data, as well as its interpretability. According to the LISREL notation, the measurement model can be described as:

$$Y = \xi\Lambda + \delta \qquad (1)$$

where

Y is the m × 1 vector of the m latent factors, in this case Environmental Friendliness, Tech Savviness, AV Favorable Perception, and AV Adoption, thus m=4.

ξ is the q × 1 vector of the q attitudinal responses measured on a 5-point Likert scale

Λ is the m × q coefficient matrix of pattern coefficients for ξ indicators on the latent factors

δ is the m × 1 vector of error terms [30].

Table 2 Statements Used in Defining the Attitudinal Latent Constructs Measurement

Model

Factor	Statement	Resources
Tech Savviness	I like to be among the first to have the latest technology.	Sentence used in the California Millennials Survey [31, 32, 25, 33]
	Having internet connectivity everywhere I go is important to me.	
	Learning how to use new technologies is often frustrating for me.	
	I like trying things that are new and different.	
Environmental Friendliness	I am committed to an environmentally friendly lifestyle.	
	The government should raise the gas tax to help reduce the negative impacts of transportation on the environment.	
	I am committed to using a less polluting means of transportation (e.g., walking, biking, and public transit) as much as possible.	
AV Favorable Perception	AVs would make traveling by car less stressful for me.	Similar measurement used in: USF AV Survey [34, 35] Puget Sound [36] University of Michigan Survey [3, 37]
	I am concerned about the potential failure of AV sensors, equipment, technology, or programs.	
	AVs would help me avoid impaired driving (e.g., under the effects of medication or alcohol).	
	I would feel comfortable sleeping while traveling in an AV.	
	AVs would make me feel safer on the street as a pedestrian or as a cyclist.	
AV Adoption	I would send an AV to pick up groceries/laundry/food orders by itself.	
	I would make more long-distance trips when AVs are available because I wouldn't have to drive.	
	I would be the first to buy an AV.	
	AVs would make it easy to share vehicles within my household because they can pick up/drop off household members on their own.	
	I would feel comfortable having an AV pick up/drop off children without adult supervision.	
	I will use AV ridehailing services alone or with coworkers, friends, or family.	

Beyond the measurement portion of the model, the structural model investigates the relationship between unobserved latent constructs (Y), exogenous variables (such as demographic characteristics), and the endogenous variables of interest. Following the same notation from the previous equation, the structural portion of the model can be described as:

$$\eta = B\eta + \mathrm{X}\Gamma + \mathrm{Y}\psi + \zeta \tag{2}$$

where

η is the 4×1 vector of endogenous variables, in this case, AV Adoption, AV Favorable Perception, Tech Savviness, and Environmental Friendliness

B is the 4×4 coefficient matrix of direct effects among endogenous variables

X is the $s \times 1$ vector of the s observed exogenous variables, here defined as a set of demographic characteristics, as well as revealed travel behavior

Γ is the $4 \times s$ coefficient matrix of regression effects of exogenous variables on the endogenous variables

Y is the $m \times 1$ vector of latent factors defined by Equation (1)

ψ is the $4 \times m$ coefficient matrix of effects of latent factors on endogenous variables

ζ is the 4×1 vector of error terms.

The present study proposes the exploration of two endogenous variables, AV Adoption and AV Perception. Both endogenous variables are continuous latent constructs measured in the measurement model based on the agreement with attitudinal statements. For the estimation of the structural equation model, MPlus was used [38]. Because the measurements are ordered categorical variables (Likert scale with 5 points, from *Strongly disagree*, through *Neutral*, to *Strongly agree*), a maximum likelihood estimator with robust standard errors was used. This specification is robust to non-normality and uses a sandwich estimator for the computation of standard errors [38]. The following formulation for the maximum likelihood estimator with robust standard errors is a simplified version of the methodology shown by Freedman [39].

If y_i is the ith observation of y, θ is a $p \times 1$ parameter vector, and the data are modeled as observed values Y_i, the likelihood function $L(\theta)$ can be seen as a function of θ, as

$$L(\theta) = \sum_{i=1}^{n} \log f_i(Y_i|\theta) \tag{3}$$

with its first and second partial derivatives with respect to θ calculated as

$$L'(\theta) = \sum_{i=1}^{n} g_i(Y_i|\theta) \tag{4}$$

$$L''(\theta) = \sum_{i=1}^{n} h_i(Y_i|\theta) \tag{5}$$

Disregarding the higher-order terms, and thus assuming $L(\theta)$ to be quadratic, the maximum likelihood can be estimated solving for the first derivative being equal to zero, so $L'(\theta) = 0$. If θ_0 is the true value of θ, the sandwich estimator is calculated assuming that $L''(\theta_0)$ can be estimated from the sample data as $L''(\hat{\theta})$. So $\hat{V}$, the Huber sandwich estimator, where the square roots of the diagonal elements are the robust standard errors, would be given by

$$\hat{V} = (-A)^{-1}B(-A)^{-1} \tag{6}$$

where

$$A = L''(\hat{\theta}) \tag{7}$$

and

$$B = \sum_{i=1}^{n} g_i(Y_i|\hat{\theta})^T \, g_i(Y_i|\hat{\theta}) \tag{8}$$

The local fit of the estimates for each of the parameters is evaluated using a t-statistic, calculated as the division of the estimated parameter by its standard error. Its two-tailed significance is then estimated from the t-distribution. The global goodness-of-fit of the model to the data is evaluated through a combination of parameters [40]. The Comparative Fit Index (CFI) uses the chi-square estimator to compare the fitted model with a baseline model; the best fit model has a CFI closest to one, and a good-fitting model has a CFI greater than 0.95. The Root Mean Square Error of Approximation (RMSEA) is an absolute measure of global fit and is also used in this study. RMSEA values closer to zero are the best, with values smaller than 0.05 indicating a good fit, and values between 0.05 and 0.10 indicating moderate fit. The Standard Root Mean

Square Residual (SRMR) is another absolute measure of fit and also indicates a good fit when smaller than 0.05 [40].

RESULTS

Figure 4 shows the standardized solution (the variances of all four factors were set to one to scale the latent constructs) for the parameters estimated in the structural portion of the model. In the hypothesized model framework, the attitudinal constructs are considered endogenous factors, which is consistent with the literature [41, 42]. Thus, Tech-savviness and Environmental Friendliness are defined as functions of basic socioeconomic characteristics while also impacting the endogenous response variables (AV Adoption and AV Favorable Perception). Socioeconomic and other exogenous factors can impact the response endogenous variables of AV Favorable Perception and AV Adoption directly and also indirectly through latent constructs.

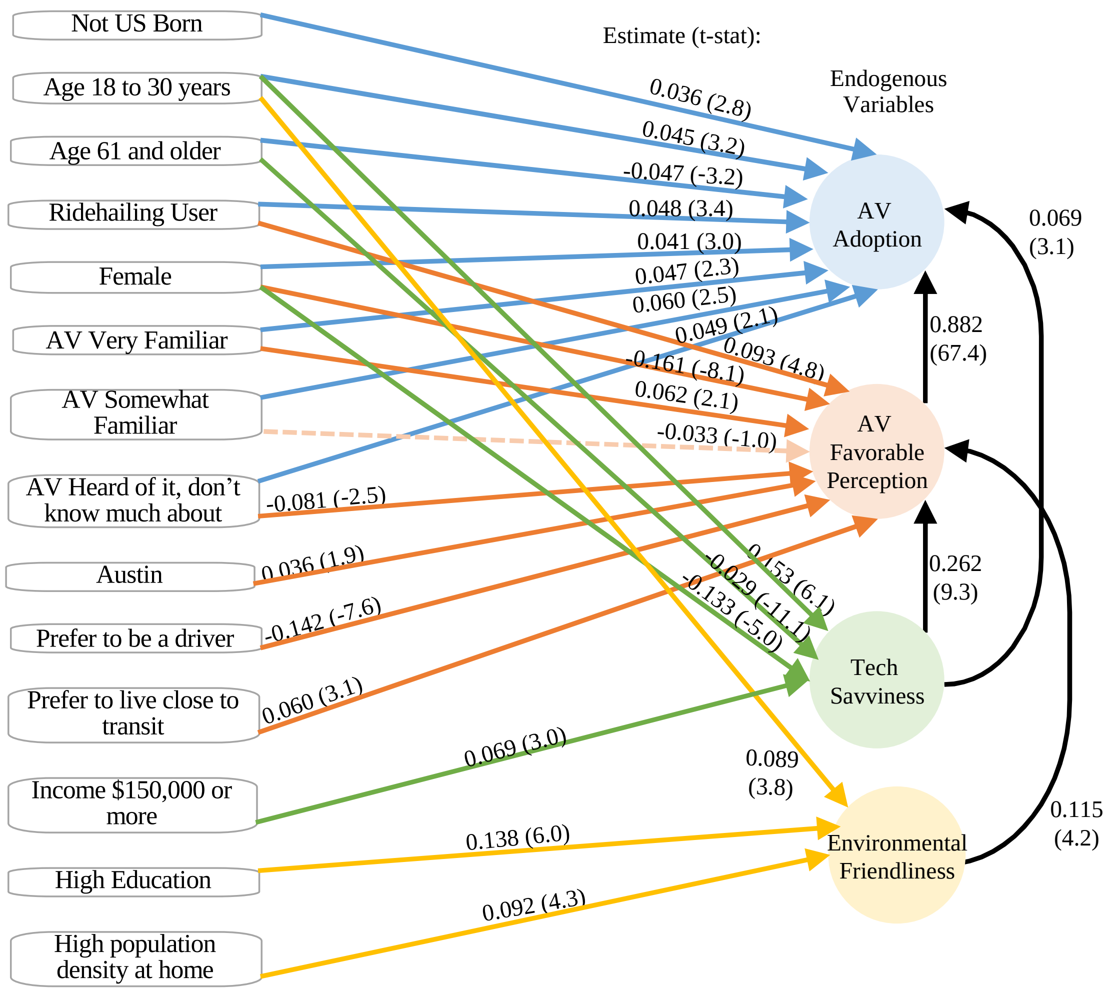

Figure 4 Structural Model Results for AV Perception and AV Adoption (Standardized Solution – using variances of latent variables, background, and outcome variables for standardization)

While being young (18 to 30 years) is associated with being more tech-savvy and environmentally friendly, being 60 years or older has a negative impact on tech-savviness. Tech-savviness was also observed to be higher among individuals of higher income and lower among women when compared to low-income individuals and men. Conversely, Environmental Friendliness was stronger among highly educated individuals (with a bachelor's degree or above), and among respondents who reported to live in high-density neighborhoods (more than 5,243 persons/square mile, which corresponds to the highest quartile of population density at the home block group in the sample).

Tech-savviness was the strongest predictor of AV Favorable perception, with the Environmental Friendliness factor also having a strong effect, although its estimated coefficient is half the size of the Tech-savviness one. While Environmental Friendliness has a significant positive impact on AV Favorable Perception, it does not significantly impact AV Adoption. Table 3 shows the breakdown in direct and indirect effects for the variables influencing AV Favorable Perception and AV Adoption, computed based on the standardized solutions of the analysis. The largest predictor of AV Adoption is AV Favorable Perception. While Tech-savviness influences AV Adoption positively, the direct effect is rather small; the indirect effect of tech-savviness, associated with a more favorable perception of AVs which is in turn associated with a more likely adoption, is much stronger.

Table 3 Total Effect Computation for the AV Adoption Model (Standardized)

	Direct Effects		Indirect Effects [a]		Total Effects [a]	
	AV Favorable Perception	AV Adoption	AV Favorable Perception	AV Adoption	AV Favorable Perception	AV Adoption
Tech-Savviness	0.262**	0.069**		0.231	0.262	0.300
Environmental Friendliness	0.115**			0.101	0.115	0.101
Female	-0.161**	0.041**	-0.117	-0.182	-0.278	-0.141
Age 18-30		0.045**	0.156	0.055	0.156	0.100
Age 61+		-0.047**	-0.026	-0.009	-0.026	-0.056
Not US Born		0.036**				0.036
Education: Bachelor's or higher			0.032	0.014	0.032	0.014
Income $150,000 or more			0.061	0.021	0.061	0.021
High Population density at home			0.021	0.009	0.021	0.009
Austin	0.036**			0.032	0.036	0.032
Private Ridehailing user	0.093**	0.048**		0.082	0.093	0.130
Familiarity: Very familiar	0.062**	0.047**		0.055	0.062	0.102
Familiarity: Somewhat familiar	-0.033*	0.060**		-0.029	-0.033	0.031
Familiarity: Only heard of it	-0.081**	0.049**		-0.071	-0.081	-0.022
Prefer to be a driver	-0.142**			-0.125	-0.142	-0.125
Prefer to live close to transit	0.060**			0.053	0.060	0.053

Note: [a] Local fitness was not computed for indirect and total effects. For the direct effects:
*Significant at a 5% level of confidence; **Significant at a 1% level of confidence.

The effect of familiarity on AV Perception is an interesting finding and focus point for this research. While those who reported being very familiar with AVs and how they work, or having experienced a real-world ride in an AV, also reported a more favorable perception of the technology, those who had heard about AVs but did not know much about them reported a less favorable perception of the technology when compared to respondents who had never heard of AVs before answering the survey. Being somewhat familiar also does not produce a significantly different impact on AV Favorable Perception compared to people with no familiarity. When it comes to AV adoption, various familiarity levels compared to no familiarity have significant positive impacts on willingness to adopt AVs in the future. This finding once again highlights how critical it is to make the public aware of the technology. Considering the AV Favorable Perception to be the strongest predictor of AV Adoption, level of familiarity also matters for willingness to use AV in the future. It is essential to present a complete and clear picture of the technology rather than let the public only hear about scattered pieces of information without reflecting the comprehensive portfolio of the automation technology. Pilot projects provide a real and clear picture of the technology to the public and therefore are recommended to be invested to facilitate a smooth and smart pathway through AV adoption.

In addition to familiarity, Tech-savviness, and Environmental Friendliness attitudes, residential location also matters when it comes to AV Favorable Perception. Preference to live close to transit and living in Austin – which is among the top ten tech hubs in the US [43] – have positive impacts on AV Favorable Perception. However, women and people who prefer to be the driver rather than passengers have significantly lower AV Favorable Perceptions.

The strongest negative effect was observed among women across various socioeconomic groups. Even though women seem to view AVs as less favorable, that does not seem to influence their willingness to adopt the technology, possibly due to their travel behavior being more conducive to the use of AVs [44]. However, the total effect of being a woman in adopting AVs is negative. Being a current ridehailing user also positively relates to both AV Favorable Perception and AV Adoption, emphasizing that current users of the on-demand mobility services will continue to use these services in an automated format more than the rest of the population probably due to the associated utility that they have already observed in their lives. These findings are consistent with those reported in the literature [5, 16]. It is worthwhile mentioning that race and ethnicity variables were not significant in any positive or negative way in this model, while people who were not born in the US have a higher willingness to adopt AVs. The analysis of the global fit of the model to the data indicates a moderate to a good fit. The estimated model has a Comparative Fit Index (CFI) of 0.844 and a Root Mean Square Error of Approximation (RMSEA) of 0.047, which indicates a good fit. The probability of the RMSEA being smaller than 0.05 is 99.9 percent. The Standardized Root Mean Square Residual (SRMR) of the model is 0.045, which further supports that the model has a good fit for the data.

CONCLUSIONS AND POLICY IMPLICATIONS

There is no doubt that automation is going to be the disruptive transformation of the transportation system in the future. Although it is not completely clear when widespread adoption of AVs will happen, it is quite certain that we will have a transition period that we should understand and plan for. Getting ready for the transition period, one main question is how various segments of the public perceive AVs and are willing to adopt AVs. The next question is about the role of familiarity and perceptions in shaping adoption choices among users. The current study aimed at understanding what factors contribute to a favorable AV perception, and how having a favorable perception of automated mobility can influence willingness to ride, in conjunction with other attitudinal aspects and socio-demographic characteristics.

The TOMNET T4 Survey data which was collected during 2019 (pre-pandemic) across four southern metro areas with 3,465 responses and an online instrument serves as the information source for this study. The Structural Equation Model estimation results enhanced the current understanding of perceptions towards AVs by investigating the role of various levels of familiarity in shaping AV perceptions controlling for other socioeconomic and attitudinal factors. While increased familiarity positively affected willingness to adopt AVs, the relationship between familiarity and perception was not as consistent. Comparing to respondents who had never heard of AVs before the survey, being very familiar with the technology had a positive impact on AV Perception while having heard about AVs without knowing much about how they work harmed AV Perception. This key finding highlights the necessity of transmitting high-quality information along with any AV education platform. Even single pieces of AV news such as accidents should accompany widespread information dissemination about the cause, rate of accident per mileage driven compared to human-driven vehicles, and much more sensible and digestible information for public knowledge.

Tech Savviness had a moderate direct effect on AV adoption in addition to a strong intermediate effect by influencing AV Favorable Perception, which in turn had a positive effect on adoption. While Environmental Friendliness positively impacted AV's Favorable Perception, its impact is less than Tech Savviness. Women, older individuals, and people who prefer to be the driver rather than passengers have negative perceptions toward AVs and less willingness to ride AVs. On the other hand, younger people, Austin and dense area residents, people who prefer to live close to transit, ridehailing users, high-income, and people with Bachelor's degrees or higher education levels have more positive AV perceptions and higher willingness to adopt AV in the future. Among all the direct and indirect impacts, the total effect of AV Favorable perception on AV adoption was significantly the largest.

Considering the large impact of AV perception on adoption controlling for other factors, it is indeed essential and worthwhile to invest in creating positive AV attitudes for a seamless, sustainable, and equitable AV adoption pathway toward the future. The findings of this study support the idea that to be effective in increasing a favorable perception of the technology, AV education campaigns should address people’s concerns and work towards promoting a more in-depth knowledge of how these vehicles work, as well as the benefits they will afford. Superficial brand awareness campaigns might have a low impact on how people feel about the technology as well as emotional news coverage of few AV crashes without any scientific judgment. According to the results of TOMNET T4 Survey (2019) across four Southern cities in the United States, a good understanding of the potential safety benefits, and how the technology is coming together and can increase mobility and accessibility of people is a more solid path to build acceptance of AVs. Pilot demonstrations with high-quality and understandable information dissemination through various channels could enhance the automation technology knowledge across all segments of the population with a special focus on women and older people.

Future studies should expand the geographic coverage of the survey, to understand how residents of other locations are planning to use AV technology. Additionally, it would be very valuable to repeat this analysis post-pandemic and explore how the new preferences built as a result of COVID-19 have influenced AV perception. Lastly, various information channels including pilot demonstrations, and online and offline streams must evaluate their effectiveness across various segments of the population so that the upcoming efforts could be revised accordingly in promoting real and scientific attitudes toward autonomous vehicles. The more people know about various dimensions of the technology, the more equipped they become when they want to make choices.

REFERENCES

[1] C. Gkartzonikas and K. Gkritza, "What Have We Learned? A Review of Stated Preference and Choice Studies on Autonomous Vehicles," *Transportation Research Part C: Emerging Technologies,* vol. 98, pp. 323-337, 2019.

[2] D. Howard and D. Dai, "Public Perceptions of Self-driving Cars: The Case of Berkeley, California," in *93rd Annual Meeting of the Transportation Research Board*, Washington, D.C., 2014.

[3] B. Schoettle and M. Sivak, "A Survey of Public Opinion about Autonomous and Self-Driving Vehicles in the U.S., the U.K., and Australia," The University of Michigan Transportation Research Institute, 2014.

[4] S. Pettigrew, C. Worrall, Z. Talati, L. Fritschi and R. Norman, "Dimensions of Attitudes to Autonomous Vehicles," *Urban, Planning and Transport Research,* vol. 7, no. 1, pp. 19-33, 2019.

[5] T. Nielsen and S. Haustein, "On Sceptics and Enthusiasts: What Are the Expectations towards Self-Driving Cars?," *Transport Policy,* vol. 66, pp. 49-55, 2018.

[6] T. U. Saeed, M. W. Burris, S. Labi and K. C. Sinha, "An Empirical Discourse on Forecasting the Use of Autonomous Vehicles Using Consumers' Preferences," *Technological Forecasting and Social Change,* vol. 158, p. 120130, 2020.

[7] J. Wu, H. Liao and J.-W. Wang, "Analysis of consumer attitudes towards autonomous, connected, and electric vehicles: A survey in China," *Research in Transportation Economics,* vol. 80, p. 100828, 2020.

[8] P. N. E. Chee, Y. O. Susilo, Y. D. Wong and A. Pernestål, "Which Factors Affect Willingness to Pay for Automated Vehicle Services? Evidence from Public Road Deployment in Stockholm, Sweden," *European Transport Research Review,* vol. 12, p. 20, 2020.

[9] Y. Peng, "The Ideological Divide in Public Perceptions of Self-Driving Cars," *Public Understanding of Science,* vol. 29, no. 4, pp. 436-451, 2020.

[10] P. Bansal, K. Kockelman and A. Singh, "Assessing Public Opinions of and Interest in New Vehicle Technologies: An Austin Perspective," *Transportation Research Part C: Emerging Technologies,* vol. 67, pp. 1-14, 2016.

[11] L. Hulse, H. Xie and E. Galea, "Perceptions of Autonomous Vehicles: Relationships with Road Users, Risk, Gender and Age," *Safety Science,* vol. 102, pp. 1-13, 2018.

[12] F. Nazari, M. Noruzoliaee and A. Mohammadian, "Shared Versus Private Mobility: Modeling Public Interest in Autonomous Vehicles Accounting for Latent Attitudes," *Transportation Research Part C,* vol. 97, pp. 456-477, 2018.

[13] JD Power, "Mobility Pipe Dreams? J.D. Power and SurveyMonkey Uncover Shaky Consumer Confidence About the Future," 2019. [Online]. Available: https://www.jdpower.com/business/press-releases/2019-q2-mobility-confidence-index-study-fueled-surveymonkey-audience. [Accessed 31 July 2021].

[14] TOMNET, "TOMNET Transformative Transportation Technologies (T4) Survey," 2020. [Online]. Available: https://tomnet-utc.engineering.asu.edu/t4-survey/. [Accessed 23 April 2021].

[15] R. Randazzo, "One Year After Fatal Uber Crash: Who Was Really at Fault? Here's the Whole Story," 2019. [Online]. Available: https://www.azcentral.com/story/news/local/tempe/2019/03/17/one-year-after-self-driving-

uber-rafaela-vasquez-behind-wheel-crash-death-elaine-herzberg-tempe/1296676002/. [Accessed 08 May 2021].

[16] P. Lavieri, V. Garikapati, C. Bhat, R. M. Pendyala, S. Astroza and F. Dias, "Modeling Individual Preferences for Ownership and Sharing of Autonomous Vehicle Technologies," *Transportation Research Record: Journal of the Transportation Research Board,* vol. 2665, no. 1, pp. 1-10, 2017.

[17] C. Haboucha, R. Ishaq and Y. Shiftan, "User Preferences Regarding Autonomous Vehicles," *Transportation Research Part C: Emerging Technologies,* vol. 78, pp. 37-49, 2017.

[18] I. Panagiotopoulos and G. Dimitrakopoulos, "An Empirical Investigation on Consumers' Intentions Towards Autonomous Driving," *Transportation Research Part C: Emerging Technologies,* vol. 95, pp. 773-784, 2018.

[19] S. Kim, G. Circella and P. Mokhtarian, "Identifying Latent Mode-Use Propensity Segments in an All-AV Era," in *99th Annual Meeting of the Transportation Research Board*, Washington, D.C., 2019.

[20] D. Sanbonmatsu, D. Strayer, Z. Yu, F. Biondi and J. Cooper, "Cognitive Underpinnings of Beliefs and Confidence in Beliefs about Fully Automated Vehicles," *Transportation Research Part F: Traffic Psychology and Behaviour,* vol. 55, pp. 114-122, 2018.

[21] P. Liu, Q. Guo, F. Ren, L. Wang and Z. Xu, "Willingness to Pay for Self-Driving Vehicles: Influences of Demographic and Psychological Factors," *Transportation Research Part C: Emerging Technologies,* vol. 100, pp. 306-317, 2019.

[22] P. Bansal and K. Kockelman, "Are We Ready to Embrace Connected And Self-Driving Vehicles? A Case Study of Texans," *Transportation,* vol. 45, no. 2, pp. 641-675, 2018.

[23] S. Ruggles, S. Flood, R. Goeken, J. Grover, E. Meyer, J. Pacas and M. Sobek, "IPUMS USA: Version 10.0 [dataset]," Minneapolis, 2020.

[24] T. Golob, "Structural Equation Modeling for Travel Behavior Research," *Transportation Research Part B: Methodological,* vol. 37, no. 1, pp. 1-25, 2003.

[25] V. Van Acker, B. Van Wee and F. Witlox, "When Transport Geography Meets Social Psychology: Toward a Conceptual Model of Travel Behavior," *Transport Reviews,* vol. 30, no. 2, pp. 219-240, 2010.

[26] S. Manca and F. Fornara, "Attitude Toward Sustainable Transport as a Function of Source and Argument Reliability and Anticipated Emotions," *Sustainability,* vol. 11, 2019.

[27] L. Montoro, S. Useche, F. Alonso, I. Lijarcio, P. Bosó-Seguí and A. Martí-Belda, "Perceived Safety and Attributed Value as Predictors of the Intention to Use Autonomous Vehicles: A National Study with Spanish Drivers," *Safety Science,* vol. 120, pp. 865-876, 2019.

[28] H. Asgari and X. Jin, "Incorporating Attitudinal Factors to Examine Adoption of and Willingness to Pay for Autonomous Vehicles," *Transportation Research Record: Journal of the Transportation Research Board,* vol. 2673, no. 8, pp. 418-429, 2019.

[29] M. Conway, L. Mirtich, D. Salon, N. Harness, A. Ross and S. Hong, "Attitudes and transport choices: A critical review and Standardised Transport Attitude Measurement Protocol (STAMP)," *In preparation.,* 2021.

[30] R. Kline, Principles and Practice of Structural Equation Modeling, 4th ed., New York, NY: The Guilford Press, 2016.

[31] G. Circella, L. Fulton, F. Alemi, R. Berliner, K. Tiedeman, P. Mokhtarian and S. Handy, "What Affects Millennials' Mobility? PART I: Investigating the Environmental Concerns, Lifestyles, Mobility-Related Attitudes and Adoption of Technology of Young Adults in California,"

2016. [Online]. Available: https://escholarship.org/content/qt6wm51523/qt6wm51523_noSplash_2c6e02b6985b0e28f86edadccdb33dc3.pdf?t=pnhnu0#:~:text=The%20result%20is%20the%20California,living%20arrangements%2C%20commuting%20and%20other. [Accessed 17 March 2021].

[32] G. Circella, A. F. K. Tiedeman, R. Berliner, Y. Lee, L. Fulton, P. Mokhtarian and S. Handy, "What Affects Millennials' Mobility? PART II: The Impact of Residential Location, Individual Preferences and Lifestyles on Young Adults' Travel Behavior in California.," 2017. [Online]. Available: https://escholarship.org/uc/item/5kc117kj. [Accessed 17 March 2021].

[33] T. Klinger and M. Lanzendorf, "Moving between Mobility Cultures: What Affects the Travel Behavior of New Residents?," *Transportation,* vol. 43, pp. 243-271, 2015.

[34] N. Menon, "Autonomous Vehicles: An Empirical Assessment of Consumers' Perceptions, Intended Adoption, and Impacts on Household Vehicle Ownership," University of South Florida Graduate Theses and Dissertations, Tampa, FL, 2017.

[35] N. Menon, "Consumer Perception and Anticipated Adoption of Autonomous Vehicle Technology: Results from Multi-Population Surveys," University of South Florida Graduate Theses and Dissertations, Tampa, FL, 2015.

[36] Puget Sound Regional Council, "Household Travel Survey Program," 2017. [Online]. Available: https://www.psrc.org/household-travel-survey-program. [Accessed 17 March 2021].

[37] B. Schoettle and M. Sivak, "Public Opinion about Self-Driving Vehicles in China, India, Japan, the U.S., the U.K., and Australia," 2014.

[38] L. Muthén and B. Muthén, "Mplus User's Guide," Los Angeles, CA, 2017.

[39] D. A. Freedman, "On the So-Called 'Huber Sandwich Estimator' and 'Robust Standard Errors," *The American Statistician,* vol. 60, no. 4, pp. 299-302, 2006.

[40] B. M. Byrne, Structural Equation Modeling with Mplus: Basic Concepts, Applications, and Programming, New York: Taylor & Francis Group, LLC, 2012.

[41] A. Rahimi, G. Azimi and X. Jin, "Examining Human Attitudes Toward Shared Mobility Options and Autonomous Vehicles," *Transportation Research Part F: Traffic Psychology and Behavior,* pp. 133-154, 2020.

[42] M. Kroesen, S. Handy and C. Chorus, "Do Attitudes Cause Behavior or Vice Versa? An Alternative Conceptualization of the Attitude-Behavior Relationship in Travel Behavior Modeling," *Transportation Research Part A: Policy and Practice,* vol. 101, pp. 190-202, 2017.

[43] Built-in, "US Tech Hubs," 2021. [Online]. Available: https://builtin.com/tech-hubs. [Accessed 31 July 2021].

[44] A. Broaddus, "Can Autonomous Vehicles Help Liberate Women?," in *6th International Conference on Women's Issues in Transportation (WIiT)*, Irvine, CA, 2019.

[45] V. Van Acker, P. Mokhtarian and F. Witlox, "Going soft: on how Subjective Variables Explain Modal Choices for Leisure Travel," *European Journal of Transport and Infrastructure Research,* vol. 11, no. 2, 2011.