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Exploring the Role of Attitude in the Acceptance of Self-driving Shuttles

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Exploring the Role of Attitude in the Acceptance of Self-driving Shuttles

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A Research Report from the National Center for Sustainable Transportation

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16. Abstract
Self-driving vehicles, as a revolution in mobility, are emerging and developing rapidly. However, public attitudes toward this new unproven technology are still uncertain. Given the significant influence of attitude toward a new technology on the intention to use it, the question arises as to why some people are in favor of this technology whereas others are not. Additionally, questions about the key attitudes influencing self-driving technology acceptance, where these attitudes come from, and how they interact with each other have not yet been addressed. This study aims to explore these research questions based on data collected from people who live or work in the West Village (WV) area of the University of California, Davis (UCD) campus after a self-driving electric shuttle was piloted in this area. structural equation modeling (SEM) was employed to explore interactions between attitude elements. The results show that affect—i.e., liking or enthusiasm for self-driving shuttles—strongly explains the acceptance of self-driving technology. A higher level of affect could be formed by strengthening an individual's trust. Additionally, trust works as an important mediator between perceived risk, usefulness, and ease of use on both affect and intention to ride self-driving vehicles. Perceived risk captured more security and functional concerns, reflecting uncertainty around current self-driving technology. The model identified important bi-directional influences between trust and affect. Significant effects of mental and physical intangibility were also shown, but each works differently on cognitive beliefs. Individuals' socio-demographic, lifestyle, and mobility characteristics also exert influences on attitude and self-driving technology acceptance.

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EXECUTIVE SUMMARY

Self-driving vehicles offer the potential to expand mobility options in a cost-effective way. Integrated with on-demand mobility, a ride-shared self-driving shuttle can effectively decrease vehicles miles traveled (VMT) by using algorithms to match riders who have different travel demands in one self-driving vehicle without influencing travel time significantly. Additionally, this technology improves vehicle accessibility, decreases vehicle ownership, requires fewer parking lots, and mitigates traffic congestion. Therefore, it has great potential for future urban transportation, especially in some closed areas such as colleges and communities. This study aims to explore its potential market and the public attitude toward it based on survey data collected from people who live or work in the West Village (WV) area of the University of California, Davis (UCD) campus. The survey questions focused on public attitudes toward shared, electric, and level-4 self-driving shuttles; such a shuttle was piloted in this area in March 2019. Although the provider, a Chinese automaker, had planned to expand the services to main campus and adjacent geographical areas after the WV demonstration, they ended the demonstration at the end of May due to the trade war between the US and China. However, during this period, residents and employees in WV were able to observe it and even share the road with it. The survey was circulated after the launch of the shuttle in March and ended at the end of May. We expect that the pilot demonstration not only aroused people's interest in our survey on self-driving shuttles, but also provided a real-world image of a self-driving vehicle for potential respondents. The insights of this research will improve understanding of attitudes toward self-driving technology, the interactions among attitudes, and their contribution to the acceptance and adoption of this new technology. The results will help transportation planners better prepare for a future dominated by automated vehicles.

This project heavily relied on a conceptual model. Based on this model, survey questions were designed and data were analyzed to determine what attitudes influence the acceptance of a self-driving shuttle. The conceptual model embraced the Technology Acceptance Model (TAM) and combined it with a widely accepted definition of attitude to enrich the exploration of the importance of attitude on the adoption of a self-driving shuttle. The survey questions were designed to measure, as the outcomes of interest: (i) attitudes toward self-driving technology and (ii) adoption intention, as well as a variety of potential explanatory factors. Because the conceptual model indicates interactions between the elements of attitude, structural equation modeling (SEM) was chosen to capture causal effects and intervening effects among them to test the hypothesized structure of underlying relationships, as well as to explore the significance and magnitudes of the impacts of explanatory factors on self-driving technology acceptance.

The data collection for this project was completed through a self-reported sampling method. The population of interest for this study is all individuals who live, work, and/or study in West

Village. West Village is home to 663 apartments and over 2000 residents. Additionally, several UC affiliated research centers are located there, including the Institute of Transportation Studies and a satellite facility for Sacramento City College. For residents, a flyer containing the direct link of the survey and Quick Response (QR) code was sent to every housing unit in West Village. Employees were recruited via an email with the same survey link and QR code sent to a list of 99 addresses provided by the research institutes in West Village. Two reminder emails were sent during the middle and at the end of the survey period. As an incentive we offered a chance to win a $100 gift card, one of 4 $50 gift cards, or one of 20 $10 gift cards from Amazon. The survey was circulated in March after the deployment of the shuttle in West Village and kept open up until the end of May, by which time 176 valid responses were collected. This equates to a low response rate of less than 0.8%.

The results show that affect—i.e., liking or enthusiasm for self-driving shuttles—which is a key concept of attitude, strongly explains the acceptance of self-driving technology. A higher level of affect could be formed by strengthening an individual's trust. Additionally, trust works as an important mediator between perceived risk, usefulness, and ease of use on both affect and intention to ride self-driving vehicles. Perceived risk captured more security and functional concerns, reflecting uncertainty around current self-driving technology. The model identified important bidirectional influences between trust and affect. Significant effects of mental and physical intangibility were also shown, but each works differently on cognitive beliefs. Individuals' socio-demographic, lifestyle, and mobility characteristics also exert influences on attitude and self-driving technology acceptance.

Introduction

Self-driving vehicles (also known as autonomous, automated, or driverless vehicles, etc.), a revolution in mobility, are emerging and developing rapidly. Six levels of vehicle automation ranging from 0 (fully manual) to 5 (fully self-driving), defined by SAE (Society of Automotive Engineers (SAE) International, 2014), were widely accepted, but only vehicles with automation levels of 4 or 5 are considered as self-driving. The up-to-date operational models of self-driving include personal self-driving vehicles, shared self-driving vehicles (shared autonomous vehicles or autonomous taxis), and ridesharing self-driving vehicles (shared autonomous vehicles with ride sharing or pooling and self-driving transit) (Litman, 2020). General benefits of self-driving vehicles are commonly believed to include that they help to improve social equity in transportation by offering service for non-drivers such as people with disabilities, children, or elderly, and can also relieve stress for drivers (Litman, 2020). Other benefits of self-driving vehicles are a gain in road capacity (Brownell & Kornhauser, 2013; Shladover, Su, & Lu, 2012), increased traffic safety (Campbell, Egerstedt, How, & Murray, 2010), smoothing of traffic flow (Rose & Ioannou, 2003), and parking cost savings (Fagnant & Kockelman, 2015), etc.

However, it is still uncertain whether self-driving vehicles will be beneficial and whether they will make up the majority of vehicles on the road in the future. Deep concerns about safety and reliability arise about this disruptive and unfolding technology. Additionally, potential drawbacks of the self-driving vehicle are likely to slow down the pace of its development and deployment even if it operates flawlessly. For example, the higher cost of technology equipment makes self-driving vehicles less affordable. Automobiles equipped with the self-driving technology are initially expected to cost $100,000 or more, and benefits such as parking savings are mostly small compared to that (Fagnant and Kockelman, 2015). Moreover, the self-driving technology is likely to induce more vehicle miles traveled (VMT), including empty vehicle driving, which may result in generating congestion (Millard-Ball, 2019). Specifically, a wide range—3%-75%—of increase in vehicle miles traveled (VMT) by personal self-driving vehicles was predicted in many studies (Harb, Xiao, Circella, Mokhtarian, & Walker, 2018; Schoettle & Sivak, 2015; Trommer et al., 2016). Although shared self-driving vehicles are more cost-effective on a per mile basis (Fagnant & Kockelman, 2015; Litman, 2020), they could also induce VMT due to the empty relocation vehicle travel, also known as deadheading (Fagnant, Kockelman, Bansal 2019). In contrast, evidence shows that ridesharing in self-driving vehicles has the potential in decrease VMT. For example, ridesharing was found to decrease empty mileage and total VMT generated by shared self-driving vehicles (Gurumurthy, Kockelman, & Simoni, 2019). Similarly, VMT decreased by adding a ridesharing system to shared self-driving services in another study (Martinez & Viegas, 2017).

Higher-occupancy self-driving transit—such as self-driving shuttles, micro transit, and neighborhood circulators that enable ridesharing—may simultaneously address environmental goals while improving transport equity and accessibility. They could make up for the potential increase in VMT induced by self-driving technology if they are used for shared rides and benefit low income people or those without cars. Such shared automated vehicles may also complement traditional transit and mitigate the challenges of first/last mile travel to transit.

Another potential area of use would be in relatively simple and closed environments—such as universities, golf courses, or local communities, etc.—where self-driving transit services could benefit from the lower cost. These applications may come first in the implementation timeline before private and shared self-driving vehicles in urban areas in the immediate future (Kaur & Rampersad, 2018; Litman, 2020).

Although self-driving vehicles for ridesharing may help make these transportation modes more economically and environmentally sustainable, the timing, scale, and future direction of their development and deployment are still unclear. To proactively prepare for this new service, understanding public acceptance and attitude toward such vehicles is a valuable starting point for policy makers to make long-range plans and investment decisions. However, the acceptance and attitude toward these new services remains uncertain, given the promise of substantial benefits on one hand but significant disruptions to the current system on the other. Some people believe that the self-driving technology will eventually substitute for human drivers and dominate the future transportation system (Baggaley), but others do not (Kaur & Rampersad, 2018). A national survey in the U.S. shows that more than half of U.S. adults express some level of worry, whereas one third are at least somewhat enthusiastic and 11% say they are very enthusiastic about driverless vehicles (Smith & Anderson, 2017). Nevertheless, higher percentages of passengers and residents show high trust level and positive attitude toward self-driving buses in Switzerland (Wicki & Bernauer, 2018). Given the significant influence of attitude toward a new technology on the intention to use it, as shown in many previous studies (Venkatesh & Davis, 2000), questions arise as to what attitudes people have toward self-driving transit services and why some people are in favor of it while others are not. Additionally, questions about the key attitudes influencing the acceptance, where these attitudes come from, and how they interact with each other have not yet been addressed.

This study aims to explore these questions based on survey data collected from people who live or work in the West Village (WV) area of the University of California, Davis (UCD) campus. The survey questions focused on public attitudes toward shared, electric, and level-4 self-driving shuttles. Such a shuttle was piloted in this area from March through the end of May 2019. During this period, residents and employees in the WV were able to observe it and share the road with it. The survey was circulated after the launch of the shuttle in March and ended at the end of May. We expect that the pilot demonstration not only aroused people's interest in our survey on self-driving shuttles, but also provided a real-world image of a self-driving vehicle for potential respondents. The survey questions were designed to measure attitudes toward self-driving technology and adoption intention as the outcomes of interest, as well as various potential explanatory factors. The insights of this research will improve understanding of attitudes toward self-driving technology, the interactions among attitudes, and their contribution to the formation of the acceptance and adoption of this new technology. The results will help transportation planners better prepare for a future dominated by automated vehicles.

Literature Review and Conceptual Model

Previous research on the acceptance of self-driving shuttles provides insights into important attitudes that influence future adoption of this technology. Important attitudes toward automated shuttles or buses, such as awareness, public acceptance, subjective perceptions of safety, in-vehicle security, emergency management were explored in some studies based on data collected from riders through surveys or interviews (Nordhoff, Winter, and Madigan et al 2018; Wicki and Bernauer, 2018; Rehrl and Zankl 2018; Salonen 2018; Salonen and Haavisto, 2019). However, qualitative or descriptive methods were employed in most of these studies and empirical evidence of important factors associated with the intention to use a self-driving transit is still lacking. In this paper, a broader set of empirical research on new technologies including the self-driving and e-commerce are thus reviewed as a basis to develop hypotheses about the factors that influence the acceptance of and attitudes toward self-driving shuttles.

Theories about technology adoption and previous studies on the adoption of transportation technologies provide a basis for the conceptual model for this study. Because a self-driving shuttle is a new technology distinct from traditional transportation modes and just emerging in the automobile market, the Technology Acceptance Model (TAM) is an appropriate theory to guide this study (Davis, 1989). It denotes that attitude toward a new technology is the main determinant of an individual's behavior intention, which directly drives the use of the technology. Attitude is represented by two beliefs, perceived ease of use and perceived usefulness of the technology. The TAM has been extended with the integration of trust and risk into the model in the context of electronic commerce as supported by some empirical studies (Pavlou, 2003). A study shows that concerns over the risks of the technology, including safety and privacy concerns, are key inhibitors to acceptance of self-driving vehicles (Benleulmi & Blecker, 2017); and public trust has been found to play a critical role in widespread adoption of this new technology (Bansal, Kockelman, & A., 2016; Kaur & Rampersad, 2018). Moreover, recent studies have confirmed that trust and perceived risk exert effects on general acceptance of and behavioral intention to use a self-driving vehicle (Liu, Yang, Wang, & Liu, 2019; Zhang et al., 2019). Perceived risk indicates consumers' uncertainty about and the seriousness of the outcome involved (Bauer, 1967). Trust generally refers to a belief in a person or thing, and it specifically denotes the confidence of consumers when faced with uncertainty (Amin & Mahasan, 2014).

Although this theory posits the importance of attitude toward the new technology as the core of the relationships, it does not explain what is in the "black box" of attitude nor the interactions between attitudinal elements. For example, where the attitude of affect—i.e., liking or enthusiasm for self-driving technology—comes from is still unknown. How it interacts with other important attitudes such as trust and perceived risk has also not been addressed. Therefore, we combined a widely accepted definition of attitude with the TAM in this study to enrich this exploration of the importance of attitude on new technology acceptance and adoption. Attitude is the mental evaluation of an object or concept, and it has three elements: cognition, affect, and conation (Day, 1972). The cognitive element denotes a person's perceptions, specifically, their knowledge, opinions, beliefs, and thoughts about the object. It also includes normative beliefs: what a person or society thinks should be done (Fishbein & Ajzen, 1975). Normative beliefs differ from general cognitive beliefs in this way: the former refer to social or personal judgments with respect to the object, whereas the latter are perceptions of properties inherent to the object (often tangible aspects). The affective or feeling element of attitude reflects whether an individual likes or dislikes an object or concept. Finally, the conative element refers to a person's intention. Among the three elements, affect is regarded by most theorists as the key element of attitude although it derives from the cognitive element.

Based on this definition, we further decomposed cognition in terms of ***perception*** and cognitive and normative ***beliefs***. Perception indicates knowledge, opinion, and thoughts. In this study, perception was measured as mental and physical intangibility of self-driving vehicles, i.e., the lacking of mental awareness of and physical experiences with self-driving vehicles. Studies have found that mental awareness of and experiences with self-driving technology is positively associated with its adoption (Becker & Axhausen, 2017), but the impact of intangibility of self-driving technology on its adoption is unclear.

Findings of a recent experimental study show that the participants' experience with the self-driving vehicles increases trust, perceived usefulness, and perceived ease of use (Xu et al., 2018). Another study on e-commerce suggests that the level of perceived risk moderates the effect of mental and physical intangibility on the adoption of a new technology (Nepomuceno, Laroche, & Richard, 2014). These findings together suggest that mental and physical intangibility exerts influence on acceptance of self-driving technology through perceived risk; meanwhile, it also has direct impact on both perceived usefulness and ease of use.

Two important elements of the TAM, perceived usefulness and perceived ease of use, as well as perceived risk and trust, which have been empirically confirmed as key factors in the acceptance of self-driving technology, belong to the category of cognitive and normative beliefs. Among them, the relationship between trust and risk has not been clearly elucidated in the literature (Mayer, Davis, & Schoorman, 1995). For example, perceived risk was hypothesized to be a function of trust in an exploration of factors influencing acceptance of electronic commerce (Pavlou, 2003). Considering that self-driving technology is far from market availability, consumers cannot build their trust based on observation or actual use of the technology; when they first encounter the technology they may perceive significant risk but then come to trust it over time. Therefore, we propose that perceived risk antecedes trust in our conceptual model, as is supported by some previous studies (Yang, Pang, Liu, Yen, & Tarn, 2015; Yousafzai, Pallister, & Foxall, 2003; Zhang et al., 2019). Further, as denoted by the original TAM theory, perceived usefulness and perceived ease of use influence attitude toward using a new technology, which includes perceived risk, trust, and affect. Importantly, the existence of a link from affect to the cognitive confidence (i.e., trust), as suggested by a previous study (Lee & Handy, 2012), will also be tested.

Previous studies show that attitudes toward self-driving technology are correlated with socio-demographic characteristics. One study found that characteristics such as being male, young, highly educated, and living in large urban areas are correlated with enthusiasm about self-driving cars (Nielsen & Haustein, 2018). Becker and Axhausen found that age and female gender negatively correlate with self-driving vehicle acceptance (Becker & Axhausen, 2017). Age negatively affects perceptions of a self-driving car, interest in using it, and intentions to use one when it becomes available (Lee, Ward, Raue, D'Ambrosio, & Coughlin, 2017). Lifestyle fit is also found to be key a predictor of acceptance of self-driving cars (Fraedrich, Cyganski, Wolf, & Lenz, 2016). This study also found that disability or physical conditions prohibiting driving were not as important as expected and that people with mobility impairment are less willing to adopt self-driving cars. Based on these findings, we also hypothesize that individual socio-demographics, physical limits, and lifestyles influence all attitudinal elements as well as self-driving use intention.

These studies help in understanding the formation of attitude and acceptance of self-driving shuttles, but they still leave some research questions open. The attitude of liking or having enthusiasm for self-driving technology is usually the focus of surveys on public attitudes toward this new technology, but rarely have factors influencing these attitudes been explored and the formation of the affect toward this new technology is still unclear. Further, because self-driving technology is still far from market commercialization, it is not an object that can be seen or felt. The role this intangibility plays and how it affects the adoption of this new technology has not been explored in previous studies (Mittal, 1999). Although previous studies also have constructed conceptual models in exploring the formation and interaction of attitude toward acceptance of self-driving vehicles, most have neglected affect, the core element of attitude (Yang et al., 2015), or have not explored the construction of attitude to clarify different attitudinal elements (Zhang et al., 2019). Our analysis explores the formation of attitudes and assesses the effects of a comprehensive set of variables on self-driving acceptance based on this conceptual framework (Figure 1). It thus aims to contribute to a better understanding of the potential determinants of attitude toward future adoption of the self-driving technology.

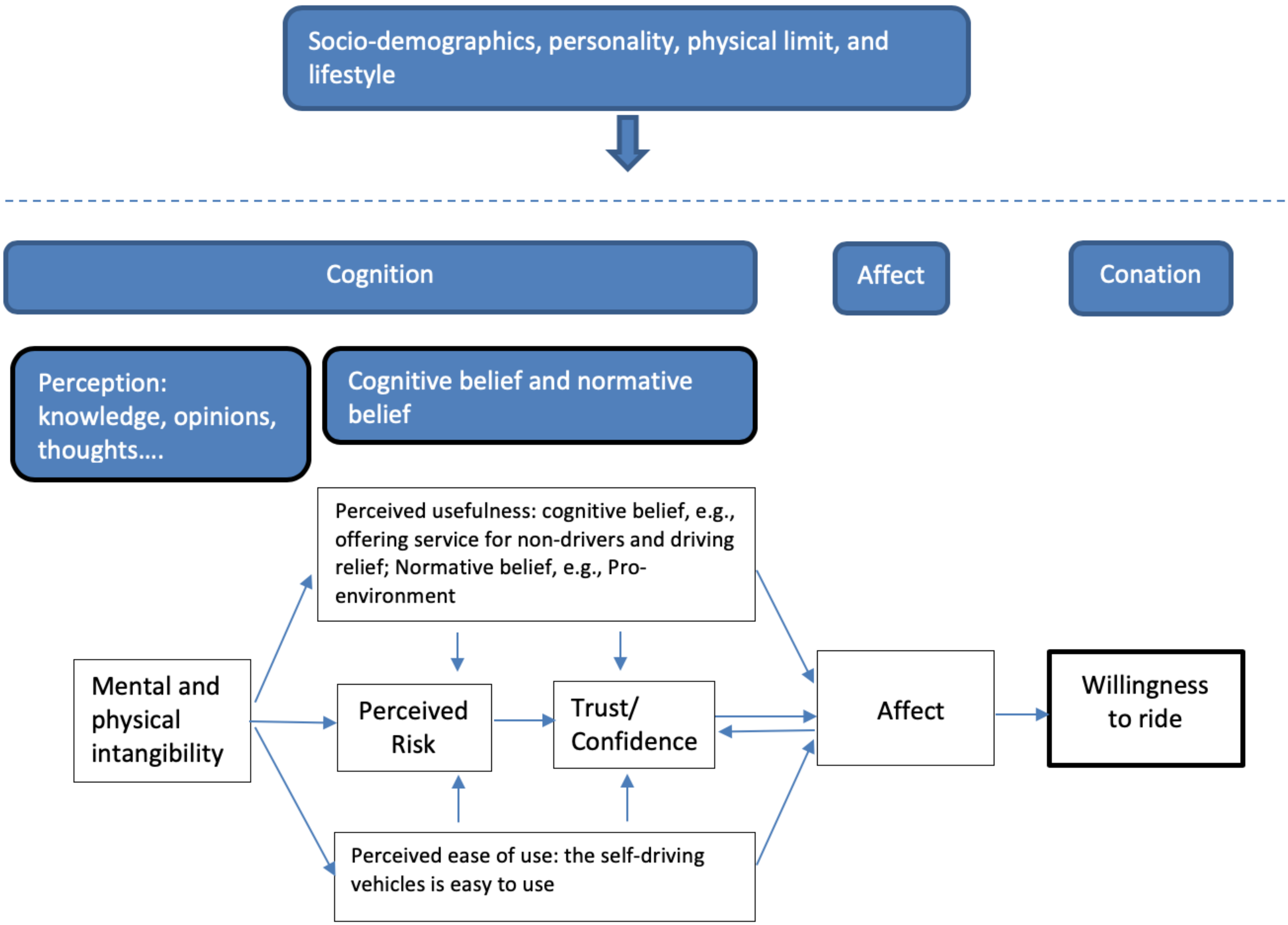

Figure 1. Hypothesized Conceptual Model

Methodology

Survey Sampling and Administration

The West Village (WV) neighborhood is home to 663 apartments and over 2000 residents. Additionally, several UC-affiliated and research centers are locate there, including the Institute of Transportation Studies. A satellite facility for Sacramento City College is located there as well. The population of interest for this study is all individuals who live, work, and/or study in West Village. For residents, a flyer containing survey direct link and Quick Response (QR) code was sent to every housing unit in West Village. Employees were recruited via an email with the same survey link and QR code sent to a list of 99 addresses provided by the research institutes in West Village. Two reminder emails were sent during the middle and at the end of the survey period. We offered, as an incentive, a chance to win a $100 gift card, one of four $50 gift cards, or one of twenty $10 gift cards from Amazon. The survey was circulated in March after the deployment of the shuttle in WV and kept open up until the end of May, by which time 176 valid responses were collected. This equates to a low response rate of less than 0.8%. Socio-demographic characteristics of the 176 respondents are shown in Table 1.

Table 1. Description of Variables Tested in the Model

Variable name	# Items [Range]	Mean (s.d.) or Percent (%)	Description
Individual characteristics			
Socio-demographic			
Age	1 [19,69]	26.7 (8.76)	Derived from the survey question: “What year were you born?”
Female	1 [0,1]	56.8%	0=Male; 1=Female.
White race	1 [0,1]	40.5%	1=White race; 0=Black or African American, Asian, Mexican or Hispanic, American Indian or Alaska Native, Native Hawaiian or other Pacific Islander, or Multiracial.
Student	1[0,1]	78.6%	1=Undergraduate or graduate student; 0=Other.
Income	2[666.7, 35,000]	3221.1 (3889.75)	The combination of the two questions “How much do you spend on housing per month?” and “About what percentage of your monthly budget do you spend on housing?” The value is the monthly expenditure on housing divided by the percentage of the monthly budget spent on housing.
Car access	1 [0,1]	29.7%	1=I own or lease or have regular access to a car; 0=I have no regular access to a car.
Home own	1 [0,1]	12.5%	1=Own the current residence; 0=Other.
Physical limit			
Walk limit	1[0,1]	6.5%	1=Have physical conditions that limit the ability to walk; 0=Do not have.
Bike limit	1[0,1]	5.4%	1=Have physical conditions that limit the ability to bike; 0=Do not have.

Variable name	# Items [Range]	Mean (s.d.) or Percent (%)	Description
Drive limit	1[0,1]	3.0%	1=Have physical conditions that limit the ability to drive; 0=Do not have.
Personality			
Easy change	1[1,5]	3.48(1.08)	Agreement that "I find it easy to adjust to change" on 5-point scale [a].
Lifestyle and transportation characteristics			
Not lifestyle	1 [1,5]	2.55(1.03)	Agreement that "The self-driving technology does not meet my lifestyle" on 5-point scale [a].
Usual walk	3 [0,1]	6.3%	1=The usual means of transportation for either of the trips in one of the three routes[b] is walking on a typical weekday with good weather; 0=Other.
Usual bike	3 [0,1]	52.8%	1=The usual means of transportation for either of the trips in one of the three routes is biking on a typical weekday with good weather; 0=Other.
Usual drive	2 [0,1]	45.5%	1=The usual means of transportation for either of the trips in one of the first two routes is driving on a typical weekday with good weather; 0=Other.
Usual bus	3 [0,1]	31.3%	1=The usual means of transportation for either of the trips in one of the three routes is bus on a typical weekday with good weather; 0=Other.
Taxi frequency	1 [1,6]	2.49 (0.76)	The response to the survey question: "How often do you take a taxi?" 1=I have never heard of it; 2=I have heard of it but I've never used it; 3=I use it less than once a month; 4=I use it several times a month but less than once a week; 5=I use it 1-2 times a week; 6=I use it 3 or more times a week.
Ride-hailing frequency	1 [1,6]	3.56(0.88)	The response to the survey question: "How often do you use a ride-hailing service?" (same scale as above)
Shared ride-hailing frequency	1 [1,6]	2.69(0.90)	The response to the survey question: "How often do you use a shared ride-hailing service?" (same scale as above)
Attitude			
Cognition: perception			
Concept familiarity	1 [1,5]	2.98(1.15)	The response to the survey question: "How familiar are you with the concept (or technology) of self-driving vehicles?" 1=Not familiar at all; 2=Slightly familiar; 3=Moderately familiar; 4=Very familiar; 5=Extremely familiar.
Ever seen	1 [0,1]	44.9%	The response to the survey question: "Not considering the new deployment of the self-driving shuttle in WV, have you seen a self-driving vehicle in operation in real life?" 1=Yes; 0=No.

Variable name	# Items [Range]	Mean (s.d.) or Percent (%)	Description
Ever interacted	1 [0,1]	17.1%	The response to the survey question: "Have you ever interacted with a self-driving vehicle in real life (not considering the new deployment of the self-driving shuttle in WV)?; 1=Yes; 0=No.
Ever ridden	1 [0,1]	11.4%	The response to the survey question: "Have you ever ridden in a self-driving vehicle in real life (not considering the new deployment of the self-driving shuttle in WV)?" 1=Yes; 0=No.
Cognition: cognitive and normative beliefs (Perceived risk, trust, perceived usefulness, ease of use, etc.)			
Street concern	1 [1,3]	1.34(0.50)	The response to the survey question: "How concerned are you about the use of WV's public streets as a proving ground for a self-driving shuttle?" 1=Not at all concerned; 2=Somewhat concerned; 3=Very concerned.
Interact concern	1 [1,3]	1.56(0.63)	The response to the survey question: "How concerned are you about sharing the road with a self-driving shuttle?" (same scale as above)
Riding concern	1 [1,3]	1.59(0.65)	The response to the survey question: "How concerned are you about riding in a self-driving shuttle?" (same scale as above)
System concern	1 [1,3]	1.91(0.74)	The response to the survey question: "How concerned are you about that the system or software of this technology may not stable or vulnerable to network attacks?" (same scale as above)
Privacy concern	1 [1,3]	1.77(0.73)	The response to the survey question: "How concerned are you about Data privacy, ID, location and destination tracking risk of disclosure of riders' private information?" (same scale as above)
Pooling concern	1 [1,3]	1.30(0.54)	The response to the survey question: "How concerned are you about sharing the shuttle with strangers?" (same scale as above)
Embrace	1[1,5]	3.97(0.95)	Agreement that "I am willing to embrace this new technology and even ride in a self-driving shuttle" on 5-point scale [a].
Comfort	1[1,5]	3.45(0.97)	Agreement that "I will feel comfortable when I am sharing the road with a self-driving shuttle" on a 5-point scale [a].
Encourage	1[1,5]	3.78(1.03)	Agreement that "I would encourage my friends to try a self-driving shuttle if available" on a 5-point scale [a].
Perceived usefulness	1[1,5]	3.78(1.00)	Agreement that "In general, I think self-driving shuttle service is useful." on a 5-point scale [a].

Variable name	# Items [Range]	Mean (s.d.) or Percent (%)	Description
Perceived ease of use	1[1,5]	4.06(0.97)	Agreement that "A smartphone app to call for the shuttle would make the service easy to use" on a 5-point scale [a].
Affect			
Like shuttle	1[1,5]	4.15(1.03)	The response to the survey question: "In general, how do you like the idea of having a self-driving shuttle service in West Village and adjacent area?" 1=I do not like it at all; 2=I like it to a small extent; 3=I like it to some extent; 4=I like it to a moderate extent; 5=I like it to a great extent.
Conation			
Willingness to ride	3[1,5]	4.10(1.17)	Derived from the responses to that "if a self-driving shuttle provided services on each of these routes, how likely would you be to ride in the shuttle?" 1=Very unlikely; 2=Somewhat unlikely; 3=Neither unlikely nor likely; 4=Somewhat likely; 5=Very likely. The value is the maximum one of the responses for the three routes.

[a] 1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree.

[b] The three routes are 1) between WV and the main campus; 2) between WV and somewhere in the city of Davis; 3) between main campus and the Amtrak station.

Variables

The variables collected in the survey were categorized based on our conceptual model into two general groups, individual characteristics and attitude. The former include socio-demographics, personality, physical limit, and lifestyle, including individual transportation characteristics. The latter denotes cognition, which consists of perception and cognitive and normative beliefs, affect, and conation. The details of all the variables tested in the model are described in Table 1.

Perception variables were designed for the purpose of examining the role mental and physical intangibility play in attitude. Mental intangibility was measured by self-reported familiarity with the self-driving concept, reflecting an individual's knowledge about this technology. Physical intangibility relates to individuals' experiences with self-driving technology, whether an individual has seen, interacted with, or ridden in a self-driving vehicle. *Cognitions* include perceived risk, trust, usefulness, and ease of use. Various aspects of risks were measured in this study. Risk types were categorized in three groups, security risk, functional risk, and privacy risk, following the study of Yousafzai et al. (Yousafzai et al., 2003). The variable "riding concern" measures functional risk due to limitations of the vehicle; "system concern" reflects security risk due to limitations of the software (Yang et al., 2015), and "privacy concern" reflects privacy risk caused by disclosure of individual private information (Yang et al., 2015). Other facets of perceived risks were also included in our study: "street concern" measures the risk due to limitations of the transport infrastructure; "interact concern" represents the risk associated with sharing the road with the shuttle; “pooling concern” is related to risks associated with pooling with strangers when riding in a self-driving shuttle. In this study, “embrace shuttle,” “comfort shuttle,” and “encourage shuttle” were designed to measure the cognition of trust, that is, willingness to make oneself vulnerable to actions taken by the trusted party based on the feeling of confidence (Gefen & Straub, 2000). The two cognitive variables, “perceived usefulness” and “perceived ease of use,” are general measures of individuals’ beliefs that self-driving shuttles are useful and easy to use. *Affect* was measured by the level of liking of the idea of having a self-driving shuttle service in the West Village area. *Conation*, represented by the willingness to ride in a shuttle, was designed to measure the acceptance of self-driving shuttles.

Model Choice

Appropriately modeling automated shuttle adoption is critical for achieving the goals of this study. Because the conceptual model indicates interactions between the elements of attitude, Structural Equation Modeling (SEM) was chosen to capture causal effects and intervening effects among them to test the hypothesized structure of underlying relationships, as well as to explore the significance and magnitudes of the impacts of explanatory factors on self-driving technology acceptance. SEM is a robust approach for capturing causal effects and intervening effects among endogenous variables and between endogenous (a variable whose value is determined by other explanatory variables) and exogenous variables (a variable whose value is not affected by other variables) (Kline, 1998). Employing this approach has several additional benefits. First, SEM is more statistically robust than a single equation model. The variables in the conceptual model are correlated with each other, and the error terms of the equations for the endogenous variables may not be independent. These concerns threaten the validity of estimates by the single equation approach. Second, it is possible to examine which relationships dominate the association between two variables by measuring the magnitudes of standardized direct ($X \rightarrow Y1$) and indirect ($X \rightarrow Y2 \rightarrow Y1$) effects. For these reasons, SEM was employed to capture the interactions between the factors as well as their influences on future self-driving shuttle adoption.

In spite of providing practical advantages, SEM is limited by its weaknesses compared to alternative statistical methods. First, SEM is a theory driven procedure, which requires a well-formed conceptual model. For this reason, our conceptual model was developed based on *a priori* theory and confirmed findings of previous literature. Second, SEM requires a relatively large sample size, e.g. $N \geq 200$ (Boomsma & Hoogland, 2001; Garver & Mentzer, 1999; Kline, 2005). It is commonly agreed that larger sample sizes, in comparison to smaller samples, result in less sampling error and decreased standard errors of parameter estimates. A relatively small sample size is thus a significant concern in this study, especially in the SEM analysis and with many explanatory variables to test. However, Muthén and Muthén (Muthén & Muthén, 2002) indicate that there is no rule of thumb in deciding on sample size for SEM analyses. Another study found that parameter estimates are more influenced by non-normality than by sample size, implying that the choice of an appropriate estimation method is more important than the requirement for a large sample size (Lei & Lomax, 2005). Moreover, two recent studies suggested small sample sizes are sufficient. Wolf et al. (2013) found that sample size requirements could range from 30 up to 450 cases and Sideridis et al. (2014) suggested a smaller sample size of 50 to 70 would be enough for a SEM model (Wolf et al. 2013; Sideridis et al. 2014)

Results

Survey Results

Descriptive analyses of the two important dependent variables affect and willingness to ride show positive public attitude toward and high acceptance level of self-driving shuttles. More than 75% respondents reported that they like the idea of having an electric self-driving shuttle in WV and adjacent areas to a moderate or great extent. About 70% respondents say that they are somewhat likely or very likely to ride in such a shuttle if its services were available between WV and main campus or somewhere in the city of Davis, implying a high public acceptance level.

Model Results

Because many of the variables as well as some factor indicators in this study are ordinal (e.g., Like shuttle, Willingness to ride, Perceived ease of use, and Street concern) rather than continuous and are thus not multivariate normally distributed, we used the estimation technique of the Mplus software package. This technique uses a weighted least squares approach to deal with the specific nature of ordinal variables when they present (Muthén & Muthén, 2007). All links specified in the conceptual model were tested empirically and only significant variables were kept in the final model (Figure 2). The standardized direct effects are presented to show the working mechanisms by which the factors exert effects on willingness to ride a shuttle. The residual variance (e in Figure 2) indicates the proportion of unexplained variance of the corresponding factor indicators. For example, the construct of Perceived Risk accounts for 50.3%, i.e., 1−.497, of the variance in Street concern. The R^2s in the figure provide the information on the amount of variance accounted for by the endogenous variables.

Three measures of model fitness were reported based on the fitting function, which is the discrepancy between observed and model-implied variance-covariance matrices. The ratio of chi-square to its degrees of freedom (χ^2/d.f.) is 1.594, which is smaller than the recommended value of 5 and implies a good model fit (Mokhtarian & Ory, 2008). The root mean square error of approximation (RMSEA) of this model is 0.061 with 90% CI of [0.047, 0.074]. RMSEA refers to the amount of error of approximation per model degree of freedom and is widely used to evaluate model fit: a value of RMSEA less than 0.10 with a maximum upper bound of the 90% confidence interval (CI) of 0.10 suggests a good fit (Browne & Cudek, 1993). Another model fitness measure, the Comparative Fit Index (CFI), has the value of 0.948 for this model. CFI compares the fit of the estimated model to that of a baseline or null model, and a value greater than 0.9 indicates an acceptable model fit (Weston, 2006). Overall, the results indicate a good fit of The SEM model.

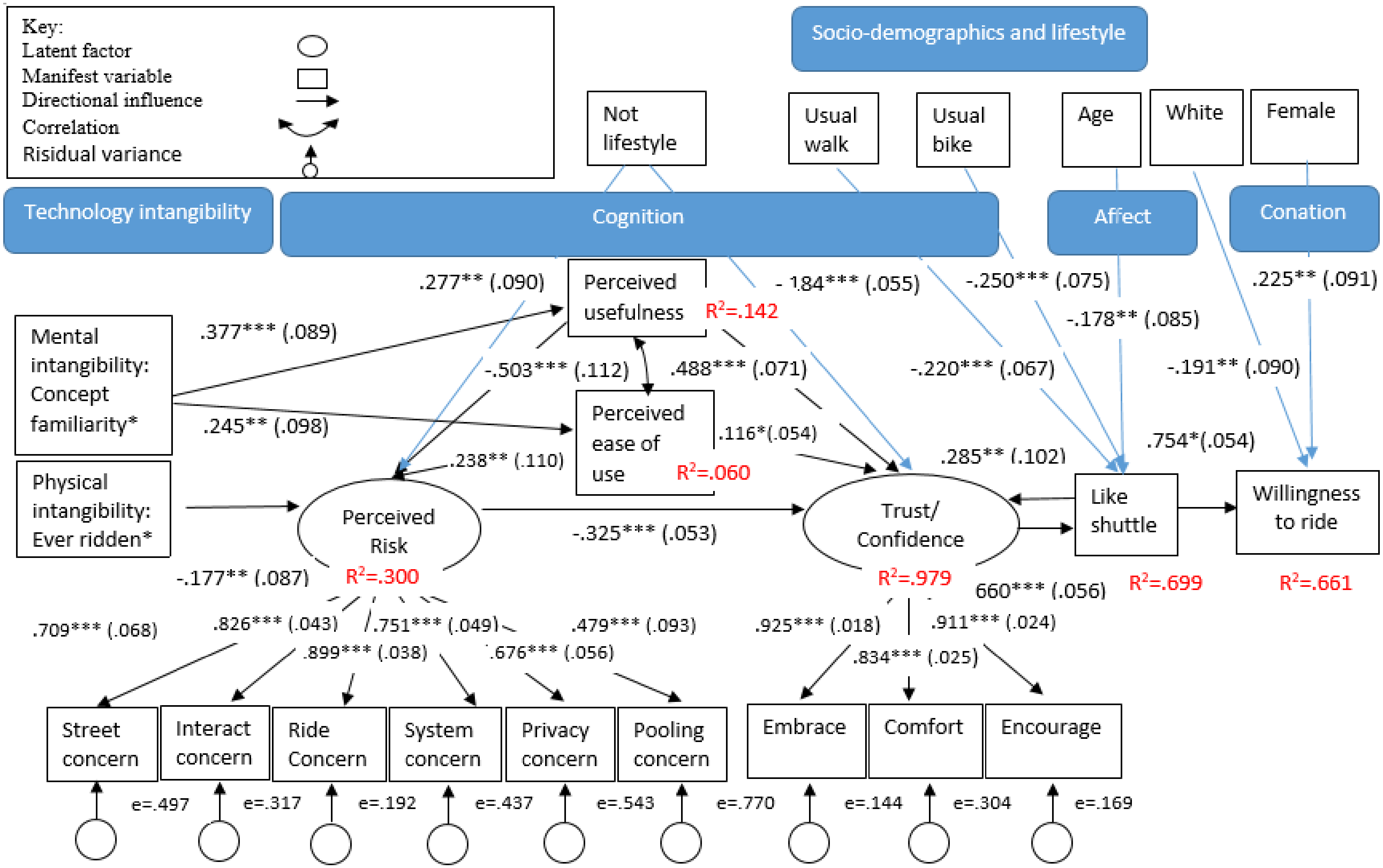

Figure 2. Standardized Parameter Estimates for the Model. Numbers in the figure are standardized coefficient/factor loadings (s.d.).

*Note that both mental and physical intangibility were measured in the opposite direction.

Latent Factor Construct

This model contains two parts: measurement models and a structural model. The former describes the relationships between latent factors and observed manifest indicators; the latter shows potential causal relationships between endogenous and exogenous variables (Muthén & Muthén, 2002). The hypothetical constructs of the measurement models in the final SEM model were guided by running the common factor analysis, which extracts different numbers of factors and determines which factors yield the most interpretable results. Specifically, the principal axis factoring method was employed to explore the dimensions of two sets of manifest attitudinal variables based on the Eigenvalue-greater-than-one criterion; each of the two sets yields one latent factor. One captures the respondents' perceived risk, including 6 manifest indicators that were designed to measure different facets of concerns aroused by a self-driving shuttle. It explains 40.8% of the total amount of variance in the set of six statements. The other factor, trust (or confidence), which explains another three manifest indicators, was extracted, and 70.2% of the total variance in the statements is explained by this factor. Then, informed by running the factor analysis, the extracted factor constructs were hypothesized as the measurement models in the final SEM. Note that all factor indicators in the model are ordinal variables. The results are presented in Figure 2. This figure shows that all the factor loadings for the two latent constructs are greater than 0.45. Factor loadings are the correlations between the manifest indicators and the latent factor. Smaller factor loadings result in larger error variances, which are the portions of variance in each measurement that do not vary with the latent factor. Stevens recommended interpreting only factor loadings with a value greater than 0.4 (Stevens, 1992), while Tabachnick and Fidell (Tabachnick & Fidell, 2007) suggest a more stringent cut-off value of 0.45.

The validity of the two latent constructs were checked. The criterion of Fornell-Larcker (Fornell & Larcker, 1981) was adopted to assess the convergent validity and discriminant validity of the measurement model. Specifically, the average variance extracted (AVE) and Cronbach's alpha were used to confirm the convergent validity. AVE measures the level of variance captured by a construct versus the level due to measurement error, and Cronbach's alpha measures the internal consistency of construct indicators. The discriminant validity indicates whether a latent construct is highly correlated with other constructs, which was assessed by checking whether the level of square root of the AVE for a latent construct is greater than all the inter-construct correlations derived from the measurement models.

In the final SEM, the AVEs are 0.55 and 0.79 for the two measurement models ("perceived risk" and "trust," respectively), which are considered good for the convergent validity of the measurement model (Fornell & Larcker, 1981). The Cronbach's alpha values are 0.79 and 0.87, both of which are greater than 0.70 for the construct of latent factors, indicating a good internal consistency for both (Raykov, 1997). The square roots of the AVEs for the latent constructs are 0.74 and 0.89, for "perceived risk" and "trust," respectively, both of which are greater than the magnitude of the correlation of the two constructs, -0.66. All together, these tests provide evidence of validity of the two latent constructs for this study.

Mental and Physical Intangibility

The model results show that technology *intangibility* has significant direct influences on *cognition*. However, mental intangibility, denoted by concept familiarity, affects perceived usefulness and ease of use, while physical intangibility determines perceived risk directly. It is notable that the experience of riding in self-driving vehicles is found significant in this model, but having seen and having interacted with self-driving vehicles do not have impacts. The results suggest that both mental familiarity and riding experiences facilitate acceptance of self-driving shuttles by increasing the level of perceived usefulness and ease of use of this technology and by decreasing the level of perceived risk.

Perceived Risk

Perceived risk represents concerns related to transportation infrastructure in a closed environment, interaction with self-driving vehicles, riding in such a vehicle, software system privacy, and pooling with strangers for shuttles specifically. Based on the magnitudes of the factor loadings, this factor expresses privacy concerns and pooling concerns less than other functional and security concerns. Experiences of ever having ridden in a self-driving vehicle and of perceived usefulness of a self-driving vehicle, especially the latter, help to significantly reduce perceived risk. However, perceived ease of use by using a smartphone app to call for the shuttle service increases the perceived risk level. It is possible that using smartphone apps may arouse security or privacy concerns, which increase the level of perceived risk. Figure 2 also shows that individual unmatched lifestyle with the self-driving technology positively correlates with perceived risk level.

Trust

Trust is formed directly by perceived risk, usefulness, ease of use, and lifestyle. Perceived risk and lifestyle unfit for self-driving technology are negatively associated with trust, whereas perceived usefulness and ease of use strengthen the feeling of trust with this new technology. Interestingly, a significant link from affect toward the self-driving shuttle to trust was shown, implying the attitude of liking this technology helps inversely to build trust and confidence.

Affect

The core element of attitude, affect, is influenced by the attitude of trust and strongly by confidence, with the second largest coefficient of all. It is also impacted by other individual socio-demographics and mobility characteristics. Older people and people who usually walk or bicycle between WV and other areas are less likely to be in favor of having self-driving shuttles in Davis.

Willingness to Ride

The attitude of affect is the key factor facilitating the acceptance of self-driving shuttles in WV and surround areas. The largest influence in the model was the influence of attitude of liking on the intention to ride a shuttle. The model also shows that people of non-white races and females have more intention to ride in shuttles than others. The latter is contrary to the finding that females are less likely to adopt self-driving vehicles (Becker & Axhausen, 2017), but another study shows that females more than males are interested in taking a smart shuttle, which is equipped with advanced technologies to track shuttle arrival information to consumers (Yimm & Ceder, 2016). Additionally, more females were found to ride transit than males in the U.S. (Goodyear, 2015). Therefore, this finding possibly suggests the gender gap in travel mode choice rather than technology adoption.

Conclusions and Discussion

This study demonstrates meaningful effects of attitudes on acceptance of self-driving shuttles for the case of the West Village area on the UC Davis campus. Affect, the core of the concept of attitude, strongly explains the acceptance of self-driving technology. As suggested by our model, a higher level of affect could be formed by strengthening an individual's trust and confidence in self-driving technology. Additionally, trust works as an important mediator between perceived risk, usefulness, and ease of use on one side and both affect and intention to ride self-driving vehicles. Perceived risk captured security and functional concerns of respondents, reflecting uncertainty around current self-driving technology. The model identified important bidirectional influences between trust and affect. Although few people had the chance to ride in the pilot shuttle in WV, The demonstration provided an opportunity for people to observe how the vehicle performs in WV under various conditions, which the model predicts would result in a higher level of trust. Significant effects of mental and physical intangibility were also shown, but each works differently on cognitive beliefs. Individuals' socio-demographic, lifestyle, and mobility characteristics also exert influences on attitude and self-driving technology acceptance.

Given that self-driving services are still far from being integrated into existing transportation systems, public acceptance of this technology is still unclear though it could benefit individuals and society. One source of doubt is that fully self-driving vehicles (level-5 automation defined by the Society of Automotive Engineers [SAE]), which can drive in any complicated conditions, will take a long time and high cost to realize. Under this circumstance, the self-driving shuttle, which operates in some relatively simple and closed environments, has great potential for market commercialization. To date, though the state of the practice of self-driving transit services is still in a very early phase, pilot demonstrations have been deployed world-wide (Cregger et al., 2018). Most demonstrations involve fully automated driving but with an operator on board (SAE level 4 automation) and operated in mixed traffic but less complicated environments (Society of Automotive Engineers (SAE) International, 2014). For example, at the University of Michigan, a driverless shuttle began to carry passengers on June 4, 2018; at the University of California San Diego, a self-driving vehicle was deployed to deliver mail on campus (Cregger et al., 2018).

How the self-driving technology would affect our society in the future is unclear, due to uncertainties of the technology and the ways that people adopt it. To proactively prepare for this new technology, policy makers need to understand public attitude to be well informed and adjust policies appropriately. Importantly, governments, especially local governments, can help shape how this technology fits into the transportation system by participating in its development and deployment. For example, they may support or be involved in pilot developments of self-driving shuttles to stir public awareness and interest. Although the cost of pilot demonstrations is high, this study suggests their importance and necessity in promoting acceptance of self-driving technology through two channels. First, by addressing mental and physical intangibility, which the demonstrations can reduce, they have a negative effect on acceptance through perceived risk, trust, and affect. Second, the trust of people would increase with the influence of pilot demonstrations.

This study provides new and potentially important insights into the nature of the attitudes that influence acceptance of self-driving vehicles, but it also points to additional research needs. First, non-response bias is a serious concern in this study. Given a very low response rate (less than 0.8%), it is possible that people, e.g., from the Institute of Transportation Studies which is located in the WV, who were more interested in this topic were more likely to respond to the survey. Another concern is that the study is fundamentally limited by its cross-sectional design. Although we have controlled for current affect, for example, it is possible that an individual's affect may increase over time when exposed to a pilot demonstration. In addition, perceived risk may be aroused more at the start of the pilot demonstration by interactions with the shuttle. The formation of perceived usefulness and ease of use are not fully explored here. Future studies should consider an even broader array of variables and aim for a larger sample size to more efficiently and effectively examine the complicated relationships between factors influencing self-driving technology adoption. Future before-and-after studies of the pilot demonstration are also needed for exploring causal relationships between attitude elements.

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Data Management

Products of Research

The information collected in this study was categorized into two general groups, individual characteristics and attitude. The former includes socio-demographics, personality, physical limit, and lifestyles. The latter denotes individual's cognition, which consists of perception and cognitive and normative beliefs, affect, and conation.

Data Format and Content

The data was saved in a SPSS file. It contains all the variables described in Table 1 in the report.

Data Access and Sharing

The data is publicly available at https://doi.org/10.25338/B8532T.

Reuse and Redistribution

Data can be reused, providing it is properly referenced. Suggested reference:

> Xing, Y., Handy, S.L., Circella, G., Wang, Y., & Alemi, F. (2019), Sociodemographic and attitude data for self-driving shuttles in West Village, UC Davis (From NCST Project " Exploring the role of attitude in the acceptance of self-driving shuttles"), UC Davis, Dataset, https://doi.org/10.25338/B8532T