Assessing Kentucky Drivers' Acceptance and Behaviors of Automated Driving

Project Final Report
(Main Report)

Submitted to

Kentucky Transportation Cabinet

by

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EXECUTIVE SUMMARY

The objective of the project was threefold: a) to assess public acceptance of Automated Vehicles (AVs) in the Commonwealth of Kentucky, b) to evaluate drivers' behaviors while engaging with automated driving, and c) to model anticipated improvements in safety from using AVs.

For objective (a), assessing the public's acceptance of AVs, we conceptualized and tested a statewide public survey in order to study three aspects of the public's views of AVs: awareness of the technology; their general attitude toward AVs; and people's affective responses associated with AV technology. While AV technology has the potential to transform the future of transportation with expected benefits such as improved driving performance, reduced fuel consumption, and expanded mobility options; adoption of the technology and these anticipated benefits may ultimately depend on the public's acceptance of AVs. Considerations such as affordability of these vehicles, people's preferences of using AV-based transportation services, residential relocation, and modality style that utilize AVs may figure prominently. Thus, our survey also assessed people's intentions for owning an AV and/or using AV-based transportation services.

For objectives (b) and (c), we conducted an AV driving simulation study to evaluate drivers' behaviors and model their safety performances while engaged in or with automated driving. This approach contributed to our understanding of the safety impacts from the drivers' reactions to Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS)[1].

For the statewide public survey, we received 673 responses from 105 of Kentucky's 120 counties (response rate: 2%, margin of error < 5%). Results revealed that 52% of the Kentucky residents who responded felt "positive" to "very positive" when asked about their general attitude toward AV technology. We also identified possible contributing factors in the acceptance of AVs and interrelationships among these factors. Based on our public survey data, we found that younger adults were more likely to have a higher overall AV acceptance level than older adults were, and it showed younger adults were more likely to claim a higher rating of exposure to AV technology. In addition, the data showed that men were more inclined to accept AV technology than women, and it showed men identified a higher rating for travel needs and affordability levels than women. We will demonstrate through our analysis of separately answered questions in the "Results" section that these factors were corollary.

When assessing Kentucky residents' willingness to purchase AVs, we found 70% of the survey respondents would consider purchasing an AV in the future. By utilizing the Structural Equation Modeling (SEM) methods, we found factors such as age, gender, affordability level, travel needs, and exposure levels to AV technology stood out as a corollary to a respondent's purchase intentions. According to the modeling results, the primary stated benefits of AVs that increased people's response rate of purchase intention included increased driving safety and freedom, increased mobility for people with disabilities (PWDs), and lower emissions. On the other hand, the major stated concerns that deterred purchase intentions included concerns regarding data privacy, there being no human control in the vehicle, uncertainties regarding interaction with conventional vehicles, and apprehensions about the transition between manual and automated driving. Interestingly, respondents who answered "no" to the question of considering the purchase of an AV in the future were given a follow-up question on whether the price was the biggest concern. Only 17% of respondents answered "yes," which suggests that the cost of an AV is not the top reason for Kentucky residents who are not considering a future purchase of an AV.

[1] defined by the Society of Automotive Engineers J3016 Levels 0-5 of Driving Automation

In terms of affordability level, most respondents surveyed who were willing to pay extra for a vehicle equipped with AV technology stated they were willing to pay more based on the level of AV technology purchased. Fewer than 4% of respondents said they would be willing to spend more than $15,000 on low to mid-level ADAS or ADS (AV Levels 2, 3, and 4); however, 8% of respondents stated they would be willing to spend more than $20,000 on the highest-level system, Level 5.

The public survey also assessed Kentucky residents' preferences for AV-based transportation services. The top three AV-based transportation services that respondents stated they would choose were: "an AV ride after consuming alcohol," "airport shuttle," and "long-distance travel." Moreover, 58% of the respondents stated they would like to see the highest-level ADS — Level 5, which can drive everywhere, in all conditions — available to serve people needing transportation who would otherwise drive impaired.

For further insights into specific populations that may benefit from AV technology, we analyzed survey responses from rural residents and PWDs. With more than half of its population living in rural areas, Kentucky is considered a rural state. According to the collected public survey data, compared with urban residents, people living in rural areas had a lower level of acceptance[2], and they did not share the same level of interest in owning an AV or using AV-based services. With 580,000 people in Kentucky living with a disability, AVs can be a solution to enhance their transportation mobility. Compared to people without disabilities, PWDs in our study showed significantly more openness to AV use to address their mobility needs. Further, survey respondents who identified as having a disability showed a higher preference in using AV-based transportation services for visiting family/friends, grocery shopping, public transit rides, and long-distance travel. Moreover, respondents who did not identify as having disabilities also showed support for using AVs to help improve the mobility of those with disabilities.

The second part of our project involved an AV driving simulation study, in which 60 participants experienced various simulated levels of driving automation in the National Advanced Driving Simulator (NADS) miniSim simulator pre-programmed with Level 0 defined by no automated driving technology, Level 2 defined by engaging with an Advanced Driver-Assistance System (ADAS), and Levels 3 and 4 defined by experiencing Advanced Driving Systems (ADS)[3]. The participants' acceptance of AVs increased markedly after they completed driving with both the Level 4 ADS and the Level 2 ADAS. A notable reduction in acceptance of AV technology was documented after the participants completed driving with Level 3 ADS. In summary, 76.7% of participants considered Level 4 ADS as the most preferred driving automation level (with 76.5% of volunteers), followed by Level 2 ADAS (20.2% of volunteers). Level 3 ADS was the least preferred (with only 3.3% of volunteers) among all tested ADAS and ADS levels. The analysis identified contributing factors that correlated with the most preferred level of driving automation. Annual household income, followed by age, stood out as the most common influential factor to those participants in determining whether Level 4 was the most preferred driving automation level.

For the third part of our project, regarding safety performances, we compared driving data and eye-tracking data from the simulations of the different AV technology levels. Compared to the benchmark of Level 0 (no automation), Level 2 (ADAS), Level 3 (ADS), and Level 4 (ADS) all outperformed simulations with no automation in terms of safety performance. Specifically, compared with having no automation, simulated traffic conflicts per minute were significantly reduced at all levels: with Level 4 ADS (93.3% reduction), Level 3 ADS (40.5% reduction), and

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[2] On a scale of 1~5, level of AV acceptance on average (urban: 3.65, rural: 3.17)
[3] SAE Levels 1 and 5 were not included.

Level 2 ADAS (70.7% reduction). Moreover, Level 4 ADS had the largest reduction in human error-related conflicts (with a 98.1% reduction), followed by Level 2 ADAS (with a 71.3% reduction) and Level 3 ADS (with a 64.8% reduction). Additionally, safety impacts from different driving behaviors were investigated. Our analysis indicated that a "regular takeover" (system requests human to take over driving) caused a 31.0 to 48.0 percent lower number of conflicts per takeover than a "failure to take over" (failure to respond to a takeover request from system) and/or an "unnecessary takeover" (human engages in driving without being requested by system). "Failure to take over" is as risky as an "unnecessary takeover" in terms of the number of traffic conflicts caused per takeover, and an "unnecessary takeover" leads to the highest severity in angles conflicts. We further evaluated how different takeover warning types ("visual only" and "visual + audible") affected safety. Level 3 analysis results showed that the "visual + audible" warning type reduced the number of conflicts per takeover compared to the "visual only" warning type by ten times and showed a 16 percent reduction in the severity of angled-conflicts[4]. As it is important to quantitatively understand AV's safety benefits when planning future AV implementation, we also developed three predictive models to estimate the improvements in safety from Level 2 ADAS, Level 3 ADS, and Level 4 ADS based on driving simulation data. Based on the predictive models, we calculated the benefit-cost ratios of each level by converting the reduction in traffic conflicts and delay into monetary values. The result indicated that Level 2 ADAS has a significantly higher benefit-cost ratio compared to Level 3 or 4 ADS as follows: L2 - 2217.62, L3 - 330.17, L4 - 669.36.

Lastly, for the public survey, an "informational" educational module was designed with an introductory video about AV technology and related textual information. For the driving simulator study, participants drove an AV in the driving simulator, experiencing various levels of automated driving, and therefore received "experiential" education about AV technology. We found that participants' AV acceptance was significantly increased after participants were informed of AV technology by both methods. Moreover, by simulated driving under Level 4 ADS-Dedicated Vehicle or under Level 2 ADAS, respectively, the increase of AV acceptance was significantly higher than the increase of AV acceptance from watching the AV introduction video only (by 62% under Level 4 and by 29% under Level 2). This indicates that hands-on AV driving experience is a more effective method to inform Kentucky residents about AV technology.

Finally, a few potential limitations about the study need to be noted. First, as noted above the result of the public survey study is based on 673 responses covering as many as 105 out of 120 counties. Although analysis indicates that the sample size is sufficient with a margin of error of only 4%, compared to Census data our sample is slightly skewed to urban dwellers (urban/rural population ratio: 1.64 vs. 1.40 from the Census data), males (58.1% vs. 48.9% from the Census data), and higher educated individuals (bachelor's degree and above: 66.7% vs. 24.2% from the Census data). The potential reason contributing to the slight difference between the survey sample and the Kentucky Census population is the survey study's main topic, Automated Driving (AV). AV may be of more interest to men and people who receive higher education. The research team has already tried its best to assure that the data can represent the real distribution of population in Kentucky by sending survey study invitation letters to randomly selected blocks of zip codes in each of the 120 counties of Kentucky without any restrictions on demographics (i.e., age, gender, household size). With the low margin of error (4%), we believe the slight skewness is difficult to be fully prevented but is acceptable to draw valid conclusions. However, we would like to bring this information up to the audience as a potential limitation. Second, this report evaluated the

[4] Angled-conflicts - vehicles traveling on perpendicular streets when one driver fails to yield the right of way to the other, such as those at conventional intersections

differences between people with and without disabilities in terms of AV acceptance and their preference ratings in AV-based transportation services, given that 580,000 people in Kentucky live with a disability. A series of power analyses were conducted to ensure that the PWDs sample size was sufficient to perform statistical analysis. However, the study did not specifically focus on collecting detailed information from PWDs (i.e., type of disabilities, the severity of disabilities), limiting the depth and breadth of our understanding of PWDs about AV technology. If we would like to further assess PWDs' mobility needs if AV is implemented, a more specific study needs to be conducted by collecting more samples from the PWDs community. Last, the 60 drivers who were involved in the driving simulator study are mostly from Jefferson County (52 from Jefferson County, one from Boyle County, one from Franklin County, one from Henry County, two from Kenton County, one from Nelson County, one from Oldham County, and one from Pendleton County). As most participants are from urban counties, the results may not fully reflect driving behaviors from rural drivers.

TABLE OF CONTENTS

1. INTRODUCTION

Not since the advent of the automobile of the late 1800's/early 1900's has society been exposed to such novel transportation technology as automated vehicle technology of today. At the beginning of the last century, most people were terrified to ride inside an automobile. Prior to these new machines, people were accustomed to using reins to both stop and steer trusted (trained) animals in order to travel about. Of course, reins were given up by a large portion of society by the 1940s for a trusted (trained) human using a mechanical steering wheel and foot pedals. Once automobiles became widely accepted as a primary form of travel, both rural trails and paths, along with urban cobblestone streets meant for horse-drawn wagons and buggies made way for both rural paved roads/interstates and the urban streets and interstates we have today meant for automobiles. With this new innovation in transportation, will people once again give up control, this time trading in a steering wheel and foot pedals for an app and voice commands? Will roadways and streets be transformed to accommodate AVs? No one knows the answers to these questions, but transportation officials who are tasked with planning for public infrastructure investments 20 years into the future would benefit by indication—seeing around the corner to find indicators of public acceptance of future trends. Public acceptance *as a primary indicator* is the subject of this study. Through statewide survey and simulator trials, this report assesses the unknowns of what Kentucky drivers think of each level of driving automation. By statistical analysis, it provides indicator rates of acceptance. This information may offer key insights for informing public officials.

Emerging Automated Vehicle (AV) technology is considered by industry experts as one of the key bundles of multiple types of sensors, artificial intelligence, and digital mapping technologies that will reshape the world. Although the coronavirus pandemic has delayed some research and development of AV components by the auto industry, according to Lux Research, "improvements in safety and efficiency are happening at all levels of vehicle automation, benefiting both consumer and commercial applications." Auto manufacturers and technology companies have invested in AV technology since as early as 2009. Twenty-nine states currently have passed AV legislation, and nine of these enable testing of AVs on public roads. As of April 2021, fifty-five manufacturers had permission to conduct their AV tests on public roads in California. However, news of crashes and fatalities involving AVs makes consumers reconsider the adoption of AV technology since they are uncertain about human drivers' responsibilities under specific levels of driving automation and liability issues.

The Commonwealth of Kentucky passed legislation in March 2018, allowing two commercial motor vehicles to "platoon," or travel in a uniform manner closely together, with electronically coordinated speeds and with commercial driver's licensed drivers being present behind the wheel in each truck. In the same year, Louisville Metro, the largest city in Kentucky, had developed an "Autonomous Vehicle Playbook" to make informed decisions regarding infrastructure, partnerships, parking, transit, and intelligent transportation systems. Both the actions by government bodies and business development indicate the anticipation and growth of AV technology in the Commonwealth now and into the future.

The findings in this research report are based on a) a statewide public survey inquiring about general attitudes of AV acceptance, purchasing intentions of AVs, intentions to use AV-based transportation services, and motivations to relocate when automated driving becomes available in Kentucky, as well as b) Kentucky residents' participation in a simulated driving experiment to test driving behaviors under different levels of driving automation.

1.1 The SAE J3016 Levels of Driving Automation Standard

To clarify the role of the human driver and answer legislative questions, SAE International, formerly the Society of Automotive Engineers (SAE), defines six levels of driving automation, which is summarized in Figure 1. In simple terms, Levels 0, 1, and 2 involve a human driver. The technology in the vehicle is there to assist the driver. This technology is known as Advanced Driver Assistance Systems (ADAS). Level 3 involves the human driver upon request by the system. Level 4 does not involve a human driver under certain operational conditions such as within interstate travel in fair weather conditions. Level 5 does not involve a human driver, as automated driving features can drive the vehicle under any circumstance. Levels 3~5 technology are known as Automated Driving Systems (ADS).

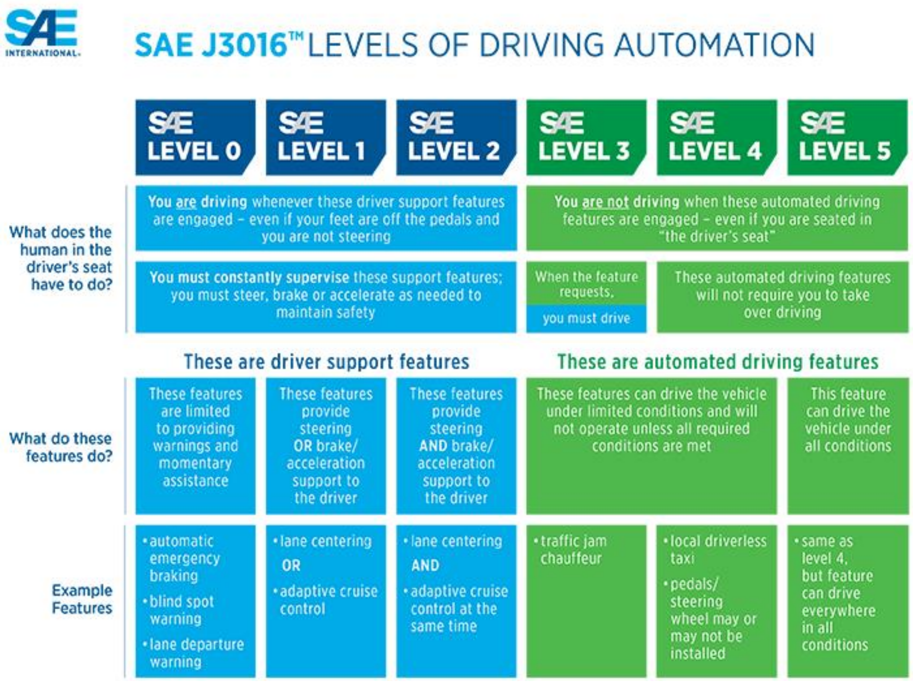


Figure 1. AV Terminology and SAE Levels

The SAE J3016 driving automation standard has been adopted by the U.S. Department of Transportation. Many auto manufacturers and technology companies are striving for developing their own automated driving systems and models at Levels 4 and 5. Some advanced driver assistance systems at Levels 0 through 2 have already been equipped in existing car models. These include:

- Level 0 — automatic emergency braking, blind-spot warning;
- Level 1 — adaptive cruise control (ACC), or lane-keeping (LK) systems;
- Level 2 — ACC and LK systems

As these AV technologies have been developed, a three-stage process of best practices has helped bring the technology forward to implementation: simulation, closed track testing, and lastly, public roadway piloting in order to make progress toward a proven product. The ADAS technologies (Levels 0-2 in the SAE chart) are considered proven market technologies, now available on most new vehicles today.

Automated Driving Systems (Levels 3-5 in the SAE chart) are still considered under development and are not yet available for direct consumer purchase. However, various forms of ADS-based transportation services are available to consumers in limited markets across the U.S. and in other countries (e.g., AV Shuttles, AV Delivery Services, AV Transportation on Demand, etc.). AV freight movement for commercial supply chain shipment is also available in limited markets.

1.2 Challenges in Adopting AV Technologies, Planning for AV, and Safety Considerations

Automakers and lawmakers deem safety to be of paramount importance before widespread adoption of AV technology will occur. Some research is focused on exploring the causes and effects of AV crashes or disengagements based on AV collision reports (submitted by manufacturers). However, the safety evaluation alone will not be enough to address the complex patterns of people's motivation and behavior for accepting and adopting AV technologies. Understanding these human factors may provide value in planning for a future with AVs for regulation and policymaking. This study aims to fill some of the research gaps in AV acceptance by expanding the investigation of acceptance from the perspectives of affordability of AVs, AV transportation services, safety, and preemptive education of AV technology. Additionally, we consider special communities such as rural areas and people with disabilities (PWDs). To help understand how much trust, usefulness, and reliability factor into a decision to use anything new, previous research, as well as methods used for this study, are provided in this section.

- **Acceptance of AV Technology:** Based on theories of diffusion of innovation (DOI) and the technology acceptance model (TAM), factors such as knowledge and other sociodemographic variables (e.g., age, gender, education level) all contribute to the attitudinal and behavioral acceptance of new technology. However, the overall impact on people's acceptance of AV technology is a combination of multiple factors. Identifying the factors and how they are logically related, then quantifying each factor's impact, proved to be a critical task accomplished through this study that sheds light on the unknowns of what Kentucky drivers think of each level of automation and how transportation may transform in Kentucky if AV technology is widely used.
- **Affordability and Willingness to Purchase an AV:** Previously published studies do not pinpoint the dynamic nature of purchasing an AV. In other words, the reasons why people may or may not consider paying for an AV have not been studied. This study goes further by assessing how much extra money Kentucky drivers may be willing to spend on specific driving automation levels.
- **AV-based Transportation Services:** Transportation services are transforming the way we get around, and it is important to understand the extent to which people would consider AV-based transportation services in the future. This study gauges people's willingness to opt for these services.
- **AV Implementation in Rural Communities:** Existing research has found that the built environment (e.g., urban/rural setting) has an impact on accepting, affording, and using AVs. People who live in rural areas have a multitude of reasons for doing so, many of which correlated with things that would influence AV acceptance, affordability, and preferences ratings. Therefore, this study aims at revealing the core reasons for how the built environment influences people's way of thinking about AVs, and the study aims to provide potential recommendations for AV implementation in rural communities.
- **People with Disabilities' Attitudes about AVs:** Kentucky's population consists of 17.3% of people with disabilities. PWDs often report having difficulty finding transportation options that work for them. People who are unable to drive due to a disability or who have limited transportation options may find it difficult to fully participate in their communities to work, achieve higher education, or gather. AV developers have been working closely with PWDs to

incorporate their needs into the design of AVs. This study aims to assess the attitudes PWDs have about AVs as a mode of transportation.

- **Safety of AVs:** In alignment with the defined levels of driving automation outlined in Figure 1, human driving behaviors while driving automation is engaged are different compared with manual driving behaviors. Existing research has mainly focused on examining the impact on safety performance when automated driving systems are engaged. However, researchers overlook other potential human driving behaviors (e.g., unintentional takeover, failure to take over), and it remains unknown how these behaviors will impact driving safety while under automated driving. Moreover, there is a lack of systematic research in evaluating the safety performance under each driving automation level.
- **Public Education about AV Technology:** AVs and other "connected" vehicles (those with technology that allows them to communicate with other systems outside the vehicle) are enabled by advancing technology that holds enormous potential to improve safety, mobility, and equity in transportation. Public acceptance of a new way to travel will once again play a significant role in our future. However, lacking basic knowledge and exposure to AVs, the general public shows skepticism and mistrust toward AV technology (PAVE, 2020). AVs' anticipated benefits will not be realized if AVs are not widely accepted, adopted, and used in our daily lives. Thus, in order to facilitate the implementation of AVs, the first and foremost task is to improve the general public's understanding of AV technology through education (Chikaraishi et al., 2020; Kaye et al., 2019). Investigating Kentucky Drivers' Acceptance of AV technology in this study has produced key indicators. While previous research has mainly focused on AV education via videos, news articles, television commercials, and hands-on experience driving a vehicle with automated technology, most of the "hands-on" experience has been with Level 2 or lower. For the limited experiences at Level 3 or higher, the experience has generally come from people sitting in an AV-operated shuttle or with a safety driver by their sides. Thus, there is a lack of research on participants able to engage with AV technology in a simulator, where they would be able to experience various levels of true automated driving. In addition, the target audiences who are receptive to AV education have not been identified. Furthermore, different AV education approaches (e.g., video-based vs. simulator-based) compared to enhancing AV acceptance remain unknown.

As mentioned, we face many challenges in introducing AV technology to the public. Many benefits such as reducing crashes due to human errors, reducing congestion, and reducing transportation-related emissions cannot be achieved if AV is not implemented properly. To tackle the challenges mentioned above, it is imperative to investigate public acceptance of AVs and drivers' behaviors during automated driving.

1.3 Research Objectives

The objectives of this study are to (1) understand how the general public (in Kentucky) accepts AV technology; (2) assess the motivations and willingness-to-purchase an AV among the survey respondents; (3) identify preferred AV-based transportation services and show the dynamic nature of using AV-based transportation services; (4) show the influences of the rural setting in accepting, purchasing, and using AVs or AV-based transportation services; (5) evaluate the differences for PWDs in accepting and using an AV or AV-based transportation services; (6) evaluate driving behaviors and compare safety as well as efficiency performance under automated driving; and (7) identify the targeted audiences who are receptive to receiving AV education and evaluate the effectiveness of different AV education approaches. Figure 2 (below) summarizes the challenges that the research team had identified from a preliminary literature review related to these objectives.

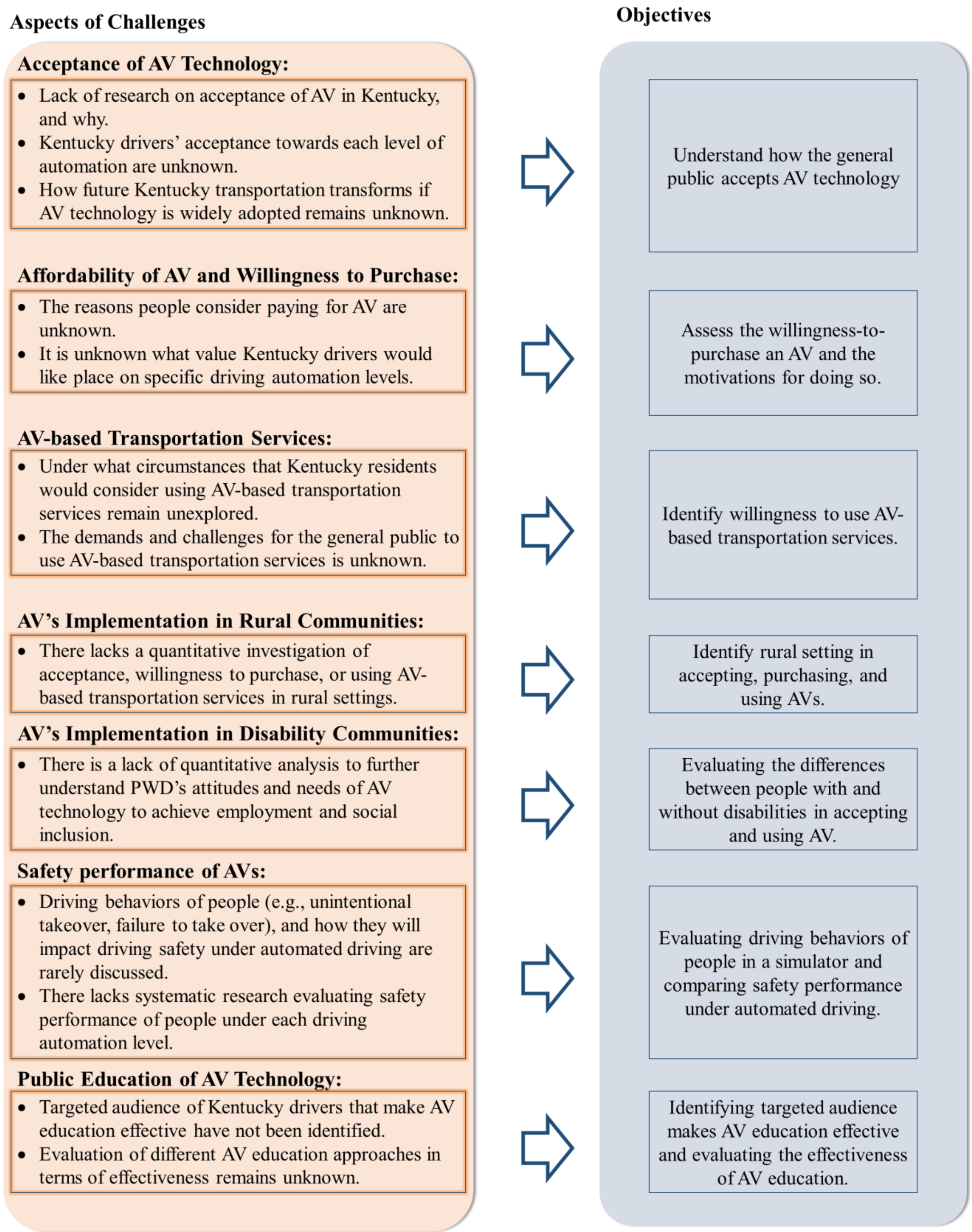


Figure 2. Research Challenges and Objectives

1.4 Intended Audience

The target audience of this report is the general public, policymakers, engineers, AV specialists, planners, and researchers. The pre-read questionnaire, a search index, a toolbox that aims to aid in finding focused topics and related chapters, and technical details are provided in the final full-length report. Hyperlinks to specific sections of the final full-length report are also provided for additional information where appropriate.

2. LITERATURE REVIEW

2.1 Public Acceptance of AVs

Existing research identifies many contributing factors that influence the overall acceptance of AVs, such as age (Charness et al., 2018; Hassan et al., 2019; Havlíčková et al., 2019; and Näslund & Gardelli, 2013), gender (Association American Automobile, 2019; Bansal et al., 2016; Hohenberger et al., 2016; and Wong et al., 2018), affordability level (Gurumurthy & Kockelman, 2020; Hardman et al., 2019; and Shabanpour et al., 2018), travel needs (Bansal et al., 2016; Kyriakidis et al., 2015; and Nielsen & Haustein, 2018), the built environment (Cao et al., 2020; Liljamo et al., 2018; Power, 2012; and Smith & Anderson, 2017), and exposure levels to AV (Charness et al., 2018; Sovacool et al., 2019; State Farm, 2016; and Wu et al., 2020).

From the general demographic perspective, existing research shows that male participants are, in general, more accepting of AVs. They are less concerned about riding in a vehicle that operates in self-driving mode part of the time (Schoettle & Sivak, 2014), feel more positive about AV technology (Hohenberger et al., 2016), and are more likely to show a greater interest in AV technology (Bansal et al., 2016). Moreover, younger drivers feel more positive about AVs in general (Charness et al., 2018), while older respondents feel more negative towards AVs (Havlíčková et al., 2019).

Exposure to AV technology is also identified as a contributing factor that influences public acceptance of AV technology. Existing studies have concluded that new technology awareness positively influences AV acceptance (Sovacool et al., 2019). Sanbonmatsu et al. (2018) found that people with the least knowledge have the most negative views towards AVs. Charness et al. (2018) concluded that prior knowledge of AV technology was associated with less concern about AVs.

2.2 Affordability of AVs

Existing research shows that men who were more likely to purchase an AV when available also reported a tendency toward ‘tech-savvy’ness (Bansal et al., 2016), and they reported a less risk-averse tendency compared with women (Wang & Zhao, 2019). However, existing research also shows that women who self-identify as having higher affordability levels when surveyed also indicated little AV driving experience, but were aware of Google’s driverless cars were willing to pay in excess of $20,000 to upgrade to Level 5 driving automation (Daziano et al., 2017).

Bansalet al. (2016) showed that a person’s willingness to purchase decreases significantly when age increases. Likewise, Shabanpour et al. (2018) found that age was highly influential in people’s AV adoption timing decisions based on survey results from an AV adoption study.

Besides age and gender, Shabanpour et al. (2018) indicated that income levels significantly influence people’s adoption preference of an AV. Liljamo et al. (2018) also identified a significant difference in attitudes towards AVs among people with different education levels. In Liljamo’s work, he identifies that education has an overwhelming tendency to positively influences people's income potential.

Moreover, existing research also sheds light on how individuals' travel behaviors could change their willingness to pay for an AV. Kyriakidis et al. (2015) indicated that people's driving frequency positively influences their willingness to pay for an AV. Wu et al. (2020) concluded that familiarity with AVs positively affected the intention to use or pay for AVs. Similar findings were also concluded by Hardman et al. (2019) and Sovacool et al. (2019).

2.3 Preferences of Using AV-Based Transportation Services

Ellis et al. (2016) concluded that young respondents between 18 and 36 are more likely to use AVs (e.g., AV-based transportation services) than other age groups. Gkartzonikas & Gkritza (2019) concluded that people over 60 and people between 18 and 25 are expected to be the most willing to pay to use automated vehicles. Also, the Bellet et al. (2018) report surmises that older adults are more likely to have different preference levels in AVs depending upon their circumstance (e.g., tendencies for decreasing physical and cognitive abilities with aging can lead to the loss of a driver's license). While Abraham et al. (2016) indicated that older adults rarely use modern transportation systems, such as car-sharing and electric bikes, Kovacs et al. (2020) concluded that AV's implications for older people are likely to be varied and influenced by policy responses.

2.4 Attitudes of People Who Live in Rural Communities Toward AVs

The built environment (e.g., living in an urban or rural setting) plays an important role in determining peoples' acceptance and purchase intentions of AVs and the willingness to use AV-based transportation services. Multiple studies have confirmed that people living in urbanized areas often show a higher positiveness toward AVs than people living in other areas (Bansal et al., 2016; Liljamo et al., 2018; Smith & Anderson, 2017). Also, Moody et al. (2020) find that respondents from more urbanized areas have a greater awareness of AV technology and anticipate fewer years before AVs will be safe enough for them to use.

2.5 People with Disabilities' Attitudes Toward AVs

Mobility is a major concern for PWDs as they frequently face challenges when moving around (Stough & Mayhorn, 2013). Existing research has attempted to understand the potential impacts of AVs on PWDs in terms of travel behaviors. Hwang et al. (2020) conducted focus groups inviting both PWDs to discuss their mobility issues as well as experts from public transit services to investigate the potential of AV's to serve PWDs. In these particular focus groups, PWDs had reserved opinions regarding AV technology. At the same time, transit experts in their focus group agreed that specific strategies should be developed to overcome any barriers for PWDs to use AV technology. Bennett et al. (2019) assessed PWDs' attitudes towards AV technology by asking open-ended questions. They found that the "levels of interest in new technology", "generalized anxiety", "intensity of a person's disability", "prior knowledge of AVs", "locus of control", and "action orientation" significantly affected PWDs' attitudes towards AVs. Milakis & van Wee (2020) analyzed the implications of AVs for the accessibility of PWDs. They showed that the increase in vehicle automation level has a positive impact on accessibility and social inclusion for PWDs.

2.6 The Role of Education

Public education has been used to increase public awareness about AVs with the intent to decrease the unknowns about automated technology. Two different educational approaches have been researched in several studies: educational videos and hands-on automated driving. For instance, Blömacher et al. (2018) asked drivers to watch videos depicting different scenarios that describe the various AV systems [(e.g., "'partial"' or "'conditional"' automated driving (Levels 2, 3)]. He then studied the effects on drivers' knowledge, mental model, trust, and acceptance. Gold et al. (2015) conducted a driving simulator experiment to investigate how automated driving might change a driver's trust in and attitude towards automation. Participants drove in a pre-programed simulator set to operate under conditional automation (Level 3) and completed a survey before and after driving in the simulator. The before and after data were compared to assess any changes to the following: trust in automation, driver safety gain, intention to use, and other measurements. The results showed increased trust in automation by participants after driving in the simulator, but the data also showed a reduction in safe driving behavior by the participants (e.g., distraction, delayed reaction to take over).

Similar research by Feldhütter et al. (2016) used both media (e.g., newspapers, magazines) and hands-on automated driving to evaluate how either may influence a participant's trust in or attitude toward automation. Thirty-one participants drove in a pre-programmed simulator set to operate under Highly Automated Driving (HAD), and they were provided with media to read. Participants reported a perception of driving enjoyment after just reading media; however, their attitudes toward automation after driving in the simulator were generally unchanged. Furthermore, participants' trust in HAD was not affected after reading media or driving in the simulator. This study showed mixed findings regarding the effectiveness of using hands-on automated driving for education. Moreover, Hartwich et al. (2018) and Liu et al. (2019) moved the investigations further beyond driving in a simulator to field testing in an automated vehicle. Hartwich et al. (2018) evaluated whether the experience of HAD can enhance drivers' trust and acceptance from driving both in a simulator and in the field.

2.7 Safety Performance of Different Automation Levels

A Level 3 automated driving system requires a human driver to take control when asked to do so. Control of the vehicle at the point of handoff from the automated system to the human driver is a critical function of safety performance. Human mastery of this function underlies trust and acceptance of the technology.

Empirical studies on automated vehicle takeover indicate that the time to collision (TTC) (TTC represents the time remaining until a collision with an obstacle is imminent. The TTC decreases until the participant brakes or changes lanes.) at the transition from automated to manual control of the vehicle is one of the essential performance measures of post-takeover longitudinal control (Zhang et al., 2019).

Existing studies have assessed a wide range of metrics to measure the safety performance of an automated vehicle. This is also referred to as the takeover performance (e.g., how many times a human has to take control of the automated vehicle while in operation). Metrics in current practice include mean, minimum, and maximum lateral/longitudinal acceleration (Clark & Feng, 2017; Feldhütter et al., 2017; Gold et al., 2016; Lin et al., 2020; and Wiedemann et al., 2018), minimum TTC (Bueno et al., 2016; Gold et al., 2016; Hergeth et al., 2016; and Wiedemann et al., 2018), minimum time to lane crossing (TLC) (Zeeb et al., 2015), lane position statistics, frequency of collision occurrence (Körber et al., 2016), steering wheel turning angle (Choi et al., 2020), and speed change (Clark & Feng, 2017; Gold et al., 2018; and Wiedemann et al., 2018). These performance measures also reflect the takeover quality.

From the perspective of the takeover request initiator, Yun & Yang (2020) evaluated the impact of takeover request modalities on time to lane change (TLC). They concluded that the "visual-auditory-haptic" warning showed a significant difference between "visual-auditory" warnings in TLC.

From the drivers' perspective, existing studies have mainly assessed TTC by looking at age and involved non-driving-related tasks (NDRTs). Gold et al. (2015) measured takeover quality by assessing TTC. They found significant differences in TTC when they perform different NDRTs (e.g., texting, psychology and cognitive neuroscience assessments). Du et al. (2019) indicated that calm leads to the best takeover performance, as demonstrated by the longest TTC. Li et al. (2018) showed that older drivers (60–81 years of age) exhibited shorter minimum TTC than younger drivers (20–35 years of age). Körber et al. (2016) investigated the effect of age on TTC. They found a statistically significant measure that more younger drivers are likely to keep a TTC below 1 second when there are 20 vehicles per kilometer. Körber et al. (2018) found that drivers who have a higher level in trusting AV technology are associated with longer takeover time and shorter minTTC than those who have a lower level in trusting AV technology.

3. METHODS

To evaluate Kentucky drivers' acceptance of AV technology through examination of the unknowns and objectives identified in Figure 2 (above), three primary methods were used in this study: (1) A public survey that included an educational video about automated vehicle technology; (2) a driving simulator programed with L0-L4 automated driving systems capabilities and an eye-tracking device; and (3) a survey of participants before and after driving in a simulator. Figure 3 summarizes each research unknown, and method(s) assessed.

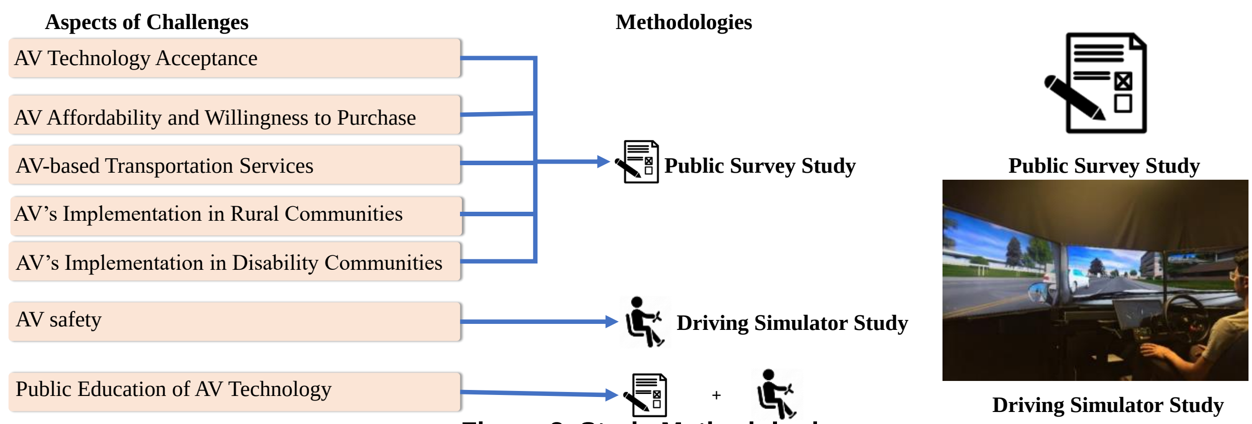


Figure 3. Study Methodologies

3.1 The Public Survey

The specific number of survey requests mailed to residents was determined by population size and urban or rural categorization of each county. As a result, a total of 35,266 public survey invitations were mailed out to Kentucky residents. An invitation letter introduced the study's purpose and provided a web link and QR code to participate in the survey. Participants could also forward the link to any residents living in Kentucky to invite them to participate by clicking the same web link or scanning the provided QR code. We also allowed survey responses by mail for those who had trouble accessing the survey questions via computer or phone. The returned survey responses came from 105 counties in Kentucky. A total of 673 survey responses were returned with a zip code in Kentucky by August 2019. There were 418 surveys returned from residents living in urban counties, and there were 255 surveys returned from residents living in rural counties. The received sample size has a margin of error of 4% at a 95% confidence level, which is statistically valid. To get more insights from people living in rural counties, Facebook ads were used to promote the survey study in rural counties, which boosted our rural survey responses from 202 to 255 (a 26.2% increase).

In addition to demographic information, the survey also asked questions about people's travel behaviors, familiarity with AV, previous experiences with riding in an AV, acceptance of AV-related attitude, and behaviors (e.g., whether they would consider living farther from work if automated driving were available, or whether they would consider being in the ridesharing business by becoming a "safety driver" in a vehicle that operated under Level 4 automation).

An AV educational video, approximately five minutes in length, was embedded in the public survey, which was designed based on the definitions of driving automation systems from SAE International, formerly the Society of Automotive Engineers (SAE International, 2016). Participants were tested on their acceptance of AVs before and after viewing the video. Since the informational video mainly focused on introducing Levels 2 through 5, we asked the survey respondents to assess their acceptance not only on the overall impression but also on the specific levels of AVs. The survey also asked questions about the perceived benefits and challenges of utilizing AVs to help people with disabilities. We received ten responses from people with disabilities and identified their most urgent transportation service needs. Please see Chapter 1.1 in the supplemental version of the report for more details.

3.2 The Driving Simulator Pre-Programmed for SAE Levels 0-4 Automation

In order to evaluate driving behaviors of people and subsequent effects on safety performance during automated driving, we collected and analyzed data from a hands-on AV driving test using a driving simulator that was pre-programmed for both varying roadway scenarios and SAE Levels 0-4 Automation: Level 0 (manual driving), Level 2 (partial automation), Level 3 (conditional automation), and Level 4 (high automation). The driving simulation environment was enabled by the National Advanced Driving Simulator (NADS) miniSim. A total of 60 volunteer Kentucky drivers completed testing in the simulator. In addition to self-reported attitudinal and behavioral intention measures, we also measured real driving behavioral data and calculated the total number of traffic conflicts and the minimum TTC to approximate actual crash numbers and crash severity. We used traffic conflicts and conflict severity because it is rare to observe AV crashes in the simulation environment. We used the Federal Highway Administration (FHWA) approved Surrogate Safety Assessment Model (SSAM) performance measures to evaluate safety. Please see Chapter 1.2 and Chapter 6 in the supplemental version of the report for more details.

3.3 Survey Before and After Driving in Simulator

In order to evaluate the effectiveness of educational methods that may lead to acceptance of AVs, questions in this survey were designed to collect people's acceptance and willingness-to-purchase (WTP) AVs before and after driving in a driving simulator pre-programmed for SAE Levels 0, 2, 3, and 4 automation.

4. RESULTS

4.1 Acceptance of AVs

Using the Structural Equation Model (SEM) to identify factors and mechanisms that may underly responses from the public opinion survey about Kentucky drivers' acceptance of AV technology, our findings focus on four perspectives: people's general attitude of AVs, purchasing intentions of AV, intentions to use AV-based transportation services, and motivations to relocate when automated driving becomes available in Kentucky.

As illustrated in Figure 4, when asked "how do you generally feel about AV technology," 52% of Kentucky residents indicated feeling either "positive" or "very positive" about AV technology, while only 21% of people indicated feeling either "negative" or "very negative." Figure 5 shows this distribution in terms of average AV acceptance by Kentucky Highway District based on the collected public survey data. For example, District 5 was color-coded as "dark-green," with an average AV acceptance being between 0.54 and 0.86. Referring to the box in the right bottom corner of Figure 5, District 5 has an average AV acceptance between "Neutral" and "Positive." In brief, District 5 and District 11 have the highest rate of positive responses to acceptance of AVs, followed by District 2, District 6, and District 7.

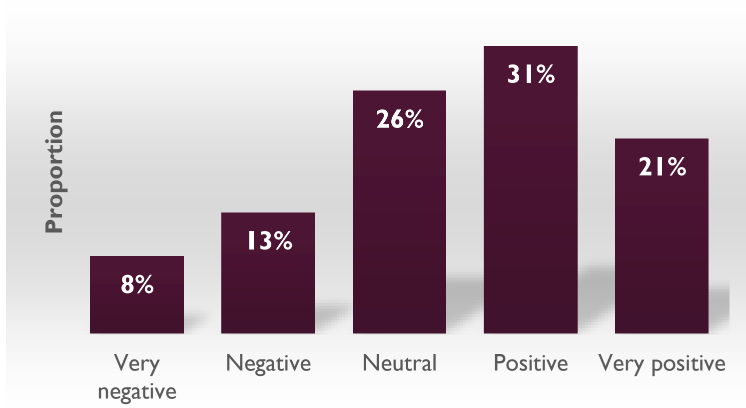
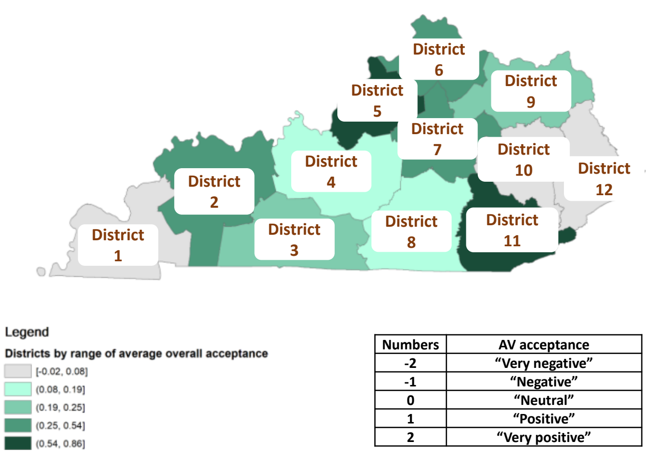


Figure 4. Overall AV Acceptance Distribution



Numbers	AV acceptance
-2	"Very negative"
-1	"Negative"
0	"Neutral"
1	"Positive"
2	"Very positive"

Figure 5. Overall AV Acceptance by Kentucky Highway Districts

We further found that where people live in Kentucky, their age and gender all appear to be factors in response tendencies when asked about AV technology. Under the categories of affordability of AV, and exposure to AVs, response rates on positivity, willingness to purchase, familiarity of AV, or experience riding in an AV were analyzed. Responded acceptance in these categories tended to be on the lower end of the scale for people who reported living in a rural area and reporting being under the age of 30. At the same time, response rates to questions in these categories tended to be on the higher end of the scale for people who reported living in urban areas and reporting being over the age of 60.

Under the additional category of "travel needs," response rates on driving more frequently were analyzed. Response rates to questions in this added category tended to be on the higher end of the scale for people who reported being male compared to female. Figure 6 shows a flowchart of these findings. Responses to the questions about riding in an AV in the category of "exposure to AVs" tended to have the most weight toward the higher end of the scale. To understand Figure 6, we use the connection among "Male," "AV familiarity," and "AV acceptance" as an example. In this case, "Male" was connected with "AV familiarity" with a "+", suggesting that men have a significantly higher AV familiarity level compared to women. Thus, being a male positively predicts people's familiarity with AV. "AV familiarity" was also connected with "AV acceptance" with a "+", suggesting that people who have higher AV familiarity levels tend to have a higher AV acceptance level. Thus, familiarity with AV positively predicts AV acceptance. Combining these two connections, we predict that men have higher AV acceptance compared to women because men are more familiar with AV technology.

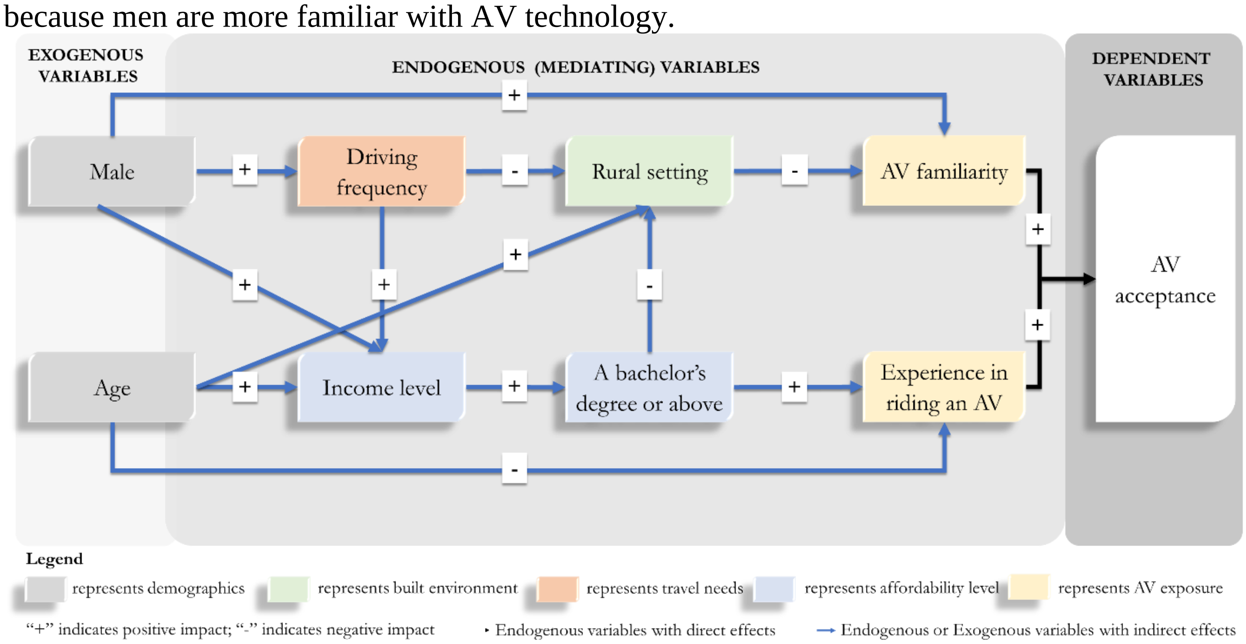


Figure 6. Nature of People with Different Ages and Genders Accept AV Technology

The public survey questions also asked respondents to rate their comfort with automation Levels 2 through 5 individually on a scale of 1 to 5, with 1 being the lowest rating and 5 being the highest rating. Responses were analyzed, and results are represented in the maps in Figure 7 below. Responses rating comfort with Level 2 automation indicates a different pattern from Levels 3, 4, and 5. However, Levels 2, 3, 4, and 5 receive higher ratings in urban counties compared to rural counties. Figure 7 illustrates the average comfort ratings with Levels 2 through 5 by county in Kentucky, where a darker color indicates a higher percentage of respondents that had a higher rating of comfort on average. Please note, counties marked with gray lines in Figure 7 represent counties for which we did not receive five or more responses in the survey.

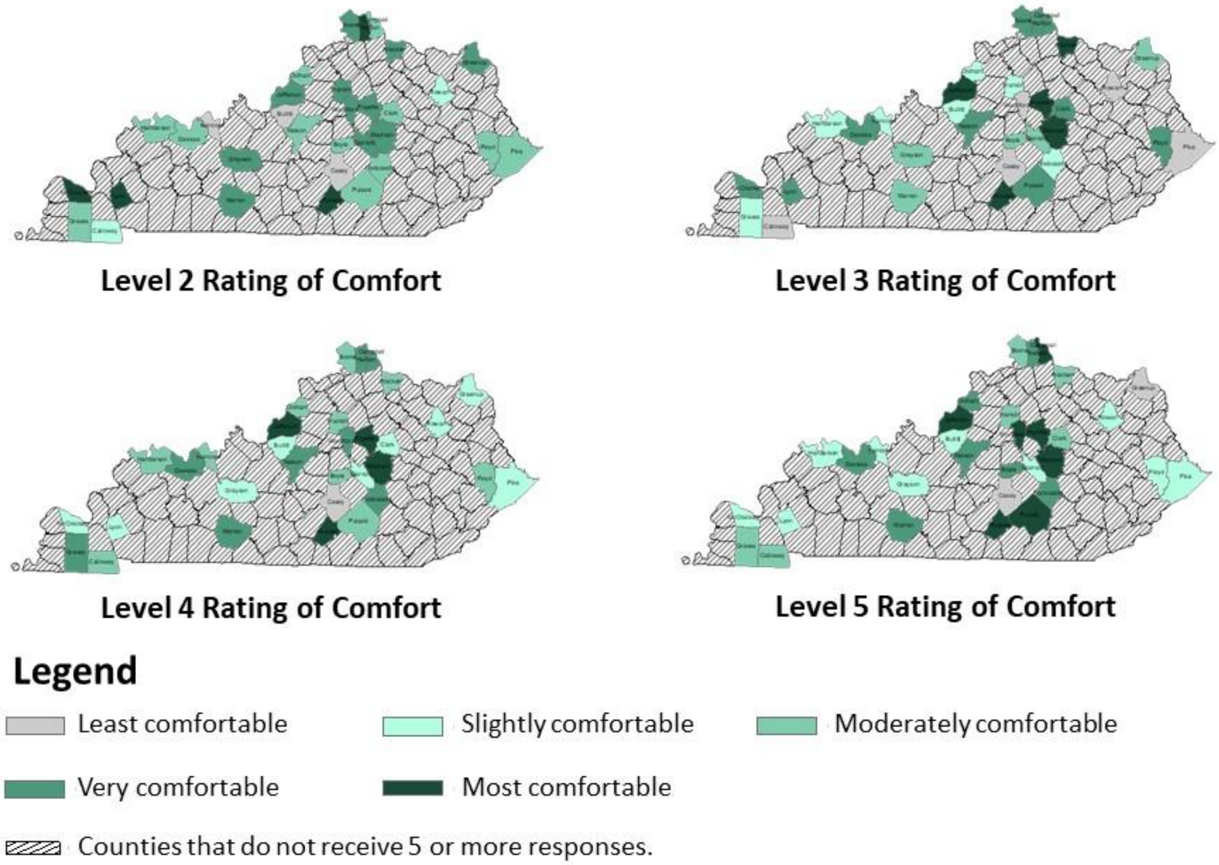


Figure 7. Average Response Rate of Comfort with Levels 2 – 5 by County

Additional survey questions asked respondents about specific levels of automation as related to commuting time. While 17.6% of survey respondents said they would live farther from work if they had a vehicle operating under Level 2 automation, 44.4% of respondents would choose to relocate if they were allowed to work and commute in a vehicle operating under Level 5. Among this group of respondents, they would most likely (47.4%) add between 15 and 30 minutes to their travel time. Figure 8 illustrates the distribution of travel time a commuter would be willing to add if using Level 5 automation. We also identified the characteristics of Kentucky drivers who would consider living farther from work if working while commuting under Level 5 is available by exploring the interrelationships among contributing factors. As a result, younger adults who have higher comfort ratings of Level 5 or living in an urban setting are more likely to live farther from work if working while commuting under Level 5 automation is available. Men who

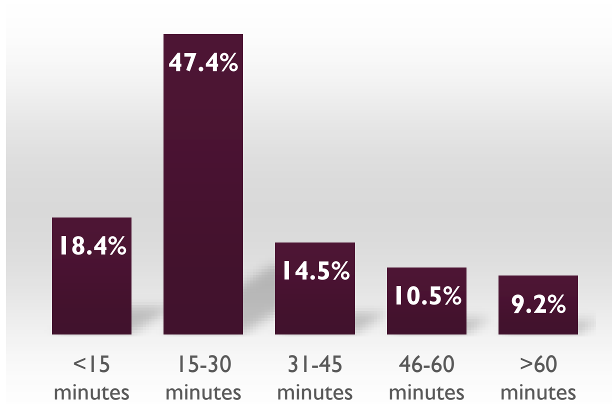


Figure 8. Distribution of Travel Time (One-Way) to be Added if Commuting under Level 5

identified with high affordability levels, a high rating of comfort in terms of Level 5, and living in an urban setting also suggest a high likelihood of relocation.

Key findings regarding how Kentucky residents accept AV technology are summarized above. Please see Chapter 3 from the supplemental version of the final report for a more detailed analysis and results.

4.2 Willingness to Purchase an AV and for what Amount

Besides the general attitude about AVs, we also asked participants about their willingness to purchase an AV in the future and what they would be willing to pay. There were 70% of our survey respondents that would consider purchasing an AV in the future. Based on these survey results, Figure 9 shows the probability distribution of Kentuckians' willingness to purchase an AV in the future. This probability distribution is broken down by Kentucky Highway Districts as a range between 0 and 1. The dark green highlighted districts (e.g., Districts 5, 6, and 11) have the highest likelihood of purchasing an AV in the future, with the probabilities of considering purchasing an AV between 66% and 74%.

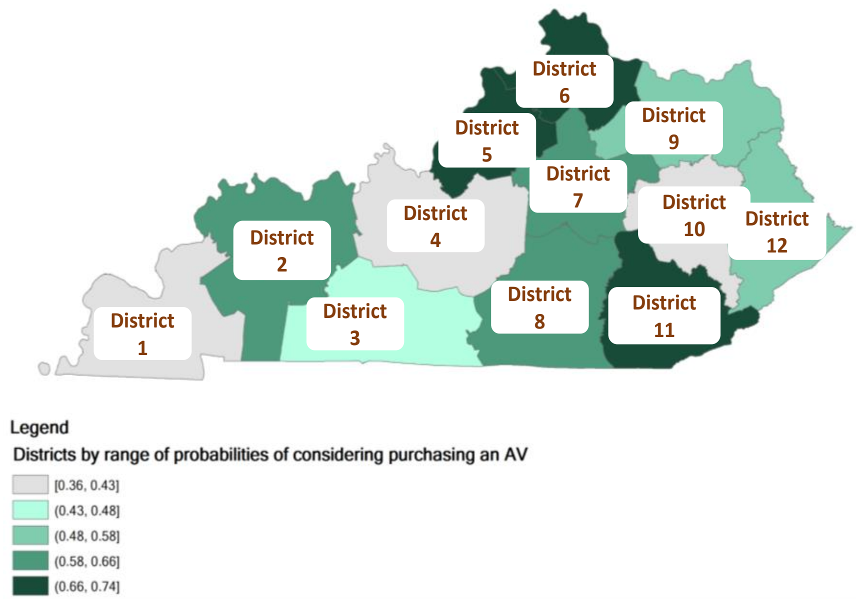


Figure 9. 'Willingness to Purchase an AV' Probability Distribution Based on Survey Results, by Kentucky Highway District

We further investigated response rates from questions related to "purchasing AVs in the future," finding that higher rates of willingness to purchase had common demographic types of age, gender, and zip code. Our research suggests the factors of higher exposure to AVs associated with younger males living in urban areas having higher acceptance rates of AVs and the likelihood to adopt for use or purchase AVs. The analysis

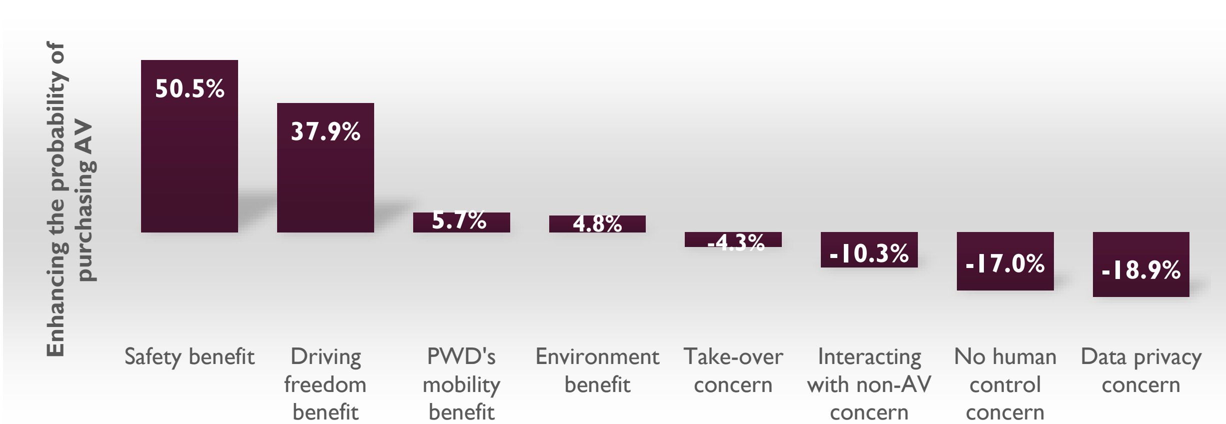


Figure10. Factors Related to Willingness to or not to Purchase an AV

of the odds ratios suggests that a level of increase in AV acceptance influences the probability of purchasing an AV by 2.214 times.

Furthermore, we also investigated how the perceptions of AV technology in terms of its benefits and concerns affect people's probability of purchasing an AV. According to the modeling results, we found that a higher rating for benefits of safety (cited as the largest benefit), driving freedom of AV, low emissions of AV, and increasing mobility levels for people with disabilities have a positive and significant impact on the probability of purchasing an AV. However, concerns of data privacy (cited as the largest concern), having no human control in the vehicle, apprehensions about interacting with conventional vehicles, and fears of AV taking over the driving (cited as the smallest concern) significantly reduce the probability of purchasing. Figure 10 illustrates the benefits and concerns of purchasing an AV, along with their impact in enhancing the probability of purchasing an AV.

Respondents who answered "no" to the question of considering a purchase of an AV in the future were given a follow-up question on whether the price was the biggest concern. As a result, only 17% answered "yes." This finding suggests that the cost of AV is not the top priority for the majority of Kentucky residents who are not considering the purchase of an AV.

In the survey questions, we asked how much extra money respondents would be willing to pay in order to own a vehicle with each SAE level of automation: Level 2 (partial), Level 3 (conditional), Level 4 (high), and Level 5 (full). The results showed that most respondents would pay no more than an additional $5,000 for any of the automated systems: Levels 2, 3, 4, or 5. Only 8% of respondents stated they would pay more than $20,000 for automated driving, even Level 5, full automation. Based on survey results, further analysis averages the amount of extra money respondents are willing to spend on Levels 2, 3, 4, and 5 as $5,954, $7,517, $9,116, and $10,712, respectively. Figure 11 illustrates the distribution of the amount of extra money respondents were willing to spend on Levels 2 through 5.

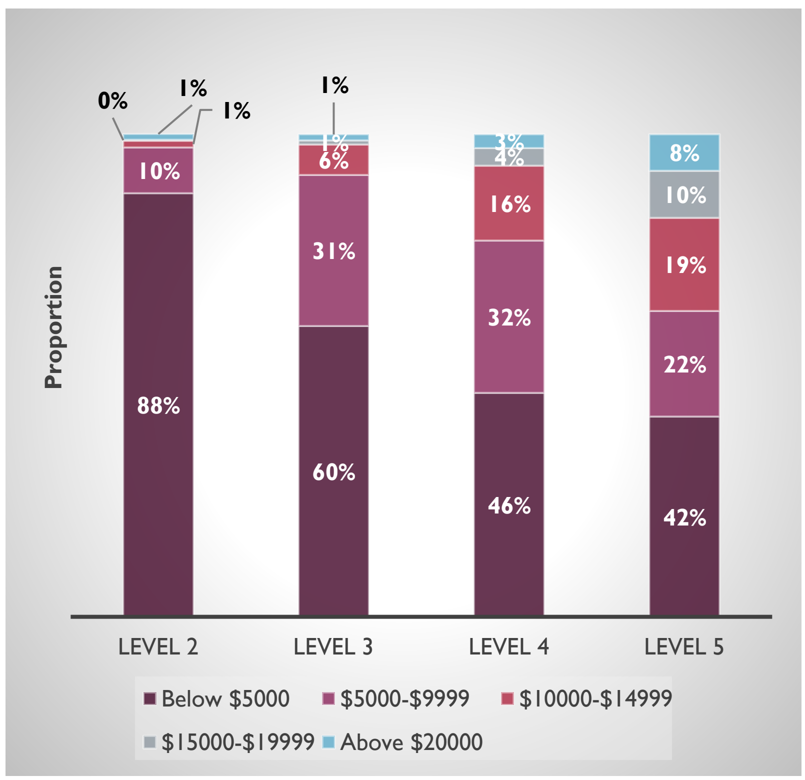
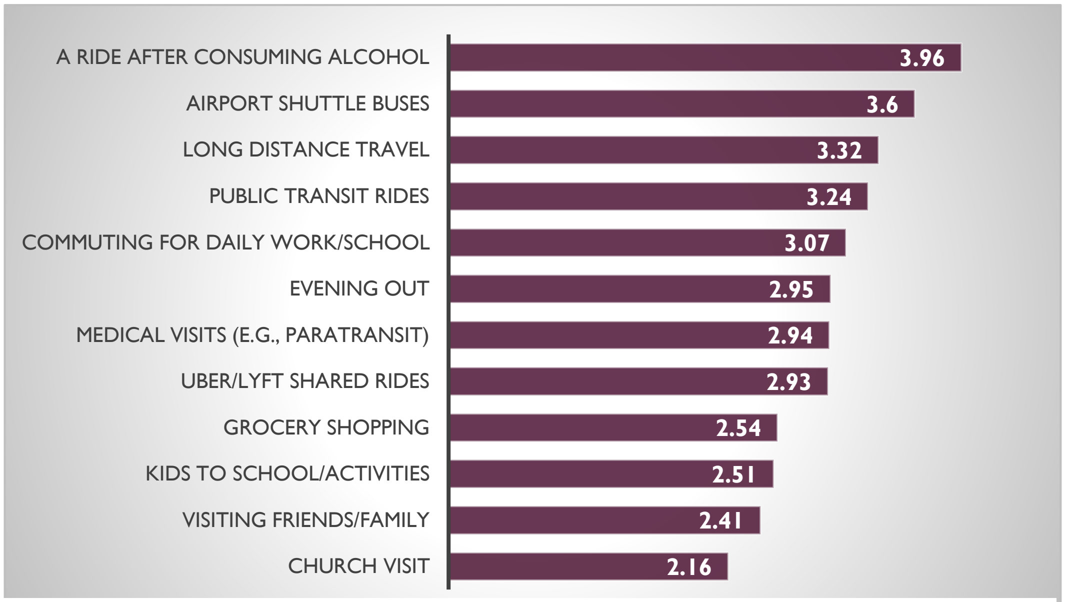


Figure 11. Distribution of the Amount of Extra Money Respondents were Willing to Spend on SAE Levels 2~5

Above are key findings regarding the affordability of and willingness-to-purchase an AV by Kentucky drivers. Please see Chapter 4 from the supplemental version of the final report for a more detailed analysis and results.

4.3 Preference in Using AV-Based Transportation Services

In the survey, we provided a list of fully AV-based transportation services and asked respondents to rate their preference for each service. The highest-rated preference for when to use AV-based transportation services was for a ride after consuming alcohol (rated 3.96 out of 5), followed by the use of an airport shuttle and long-distance travel. Figure 12 illustrates the average rating for preference to use fully AV-based transportation services.



Rating scale: 1=Least preferred, 2=Slightly preferred, 3=Moderately preferred, 4=Very preferred, and 5=Most preferred.

Figure 12. Average Ratings for Preferred AV-based Transportation Services

Moreover, we asked respondents whether they support using AVs as a solution to reduce the number of crashes caused by impaired driving. The majority of Kentucky respondents (71%) support this idea, and 58% of the survey respondents also support utilizing Level 5 full automation to serve people needing transportation who would otherwise drive impaired.

Again, through SEM analysis, some key findings showed the corollary between older adults tended to be less likely to prefer to use AV-based transportation services compared to younger adults and for older adults tending to have less familiar with AV technology. Also, the analysis showed the corollary between men tended to have a higher average preference rating of using AV-based transportation services compared to women and men reporting to having higher travel needs and higher AV familiarity levels. Future efforts at education and engagement with AV-based transportation services may wish to target those in older age groups and women. The analysis also shows that participants from urbanized areas reported a higher preference for using AV-based transportation services in general. In particular, analysis shows that respondents from the Kentucky Highway District 5 and District 6 had a higher rating of acceptance for AV-based (Level 5) transportation services.

One survey question asked if respondents would be willing to become a “safety driver” in an automated Uber/Lyft under Level 4 (high) automation; 60% of respondents chose “yes.”, with 19% choosing “Yes in any cases” and 41% choosing “Yes if incentive (waived/reduced ride-sharing fee) is provided”. A classification tree model was developed in identifying characteristics that contribute to a higher likelihood of becoming a “safety driver.” As such, Kentucky drivers who report being more comfortable with Level 4 (high) automation, having existing AV familiarity, and having a bachelor’s degree or above are more willing to become a “safety driver.” Through another outcome of the classification tree model, men appeared to be more inclined to become a "safety driver" compared to women.

Above are the key findings in terms of ratings for preferred AV-based transportation services. Please see Chapter 5 from the supplemental version of the final report for a more detailed analysis and results.

4.4 Urban vs. Rural: Accepting, Purchasing, and Using AVs

Consistent with the previous literature, we found that living in an urban or rural setting plays a vital role in new technology adoption and implementation. Below, we summarize our key findings related to people living in urban or rural communities.

When we focused on urban vs. rural response rates in our analysis of accepting AV technology, we detected a distinction between the two. Figure 13 breaks down the response rate difference between rural and urban residents. The rural and urban classifications are based on each county's population: 60.8% of the respondents from urban areas indicated feeling positive about AV technology, compared to 42.7% of responses from rural areas who felt positive about AV technology. Also, our public survey data suggests that more rural respondents hold negative feelings about AV (28.1%) than urban respondents (15.4%).

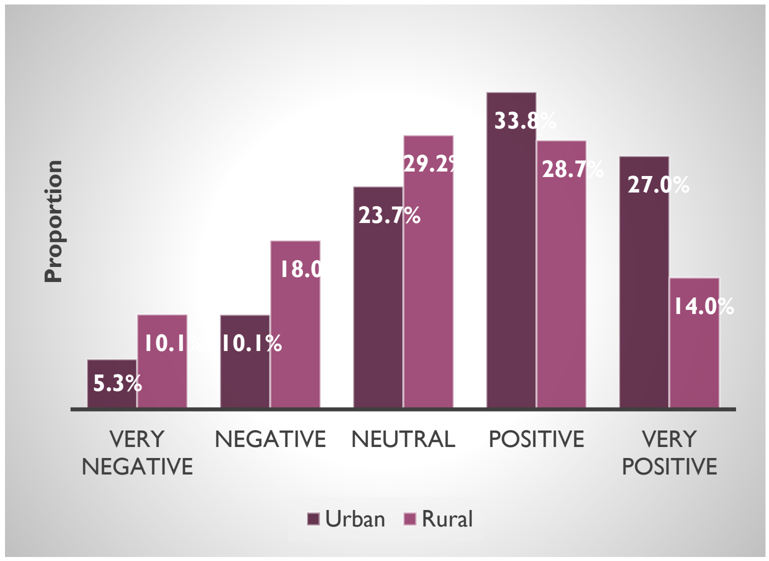
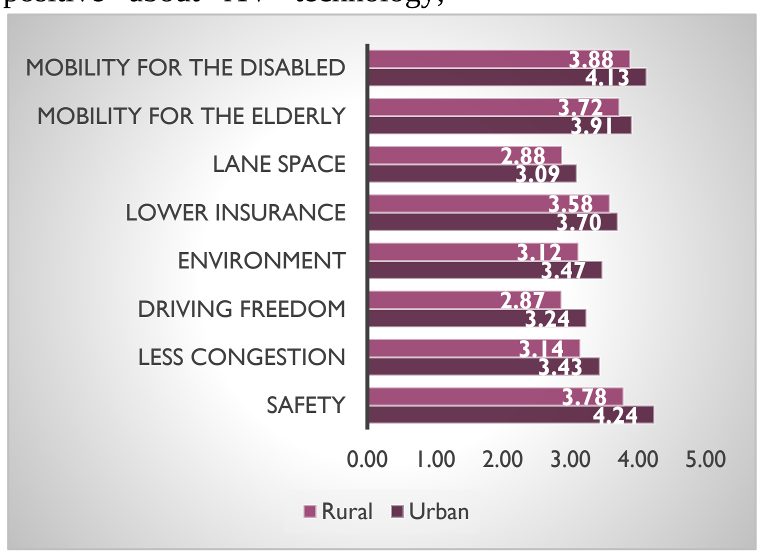


Figure 13. Distribution of Overall AV Acceptance by Urban and Rural Respondents

Furthermore, both urban and rural respondents have different evaluations on the potential benefits and concerns for AV implementation, as illustrated in Figures 14 and 15. Both urban and rural residents believe the top three benefits of AV are: safety, improving mobility for the elderly or older adults, and improving mobility for PWDs. For respondents who live in urban areas, the top three concerns of AV are safety

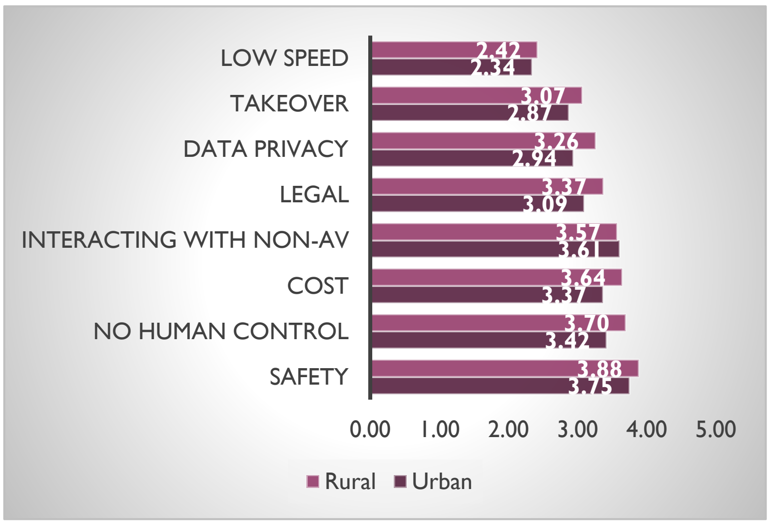


Rating scale: 1=Least beneficial, 2=Slightly beneficial, 3=Moderately beneficial, 4=Very beneficial, and 5=Most beneficial.

Figure 14. Benefit Ratings of AV between Urban and Rural Respondents

consequences of equipment/system failure, riding in a vehicle with no driver controls, and interacting with conventional vehicles, pedestrians, or cyclists on the road. In comparison, those living in rural areas are concerned with riding in a vehicle with no driver controls, followed by safety consequences of equipment/system failure and concerns of AVs being more expensive than conventional vehicles. Please see Chapter 3.5 of the supplemental version of the report for a more detailed analysis and results on ratings of the potential benefits and concerns about AVs.

Regarding purchasing an AV, based on the survey, our analysis shows that living in a rural setting reduces the probability of purchasing an AV by 23.2%. In addition, the collected public survey data suggest that participants from rural areas reported a significantly lower preference for using AV-based transportation services. The potential reason can be attributed to the differences between urban and rural respondents in rating their comfort with Level 5 automation. Analysis of the odds ratio of factor "rural setting" indicates that living in an urban setting increases the probability of having a higher average preference rating using AV-based transportation services by 6.849 times (for more details, see Chapter 5.1 from the supplemental report). Based on the survey results, people living in rural areas are also less likely to consider living farther from work if they are allowed to work while commuting in Level 5 AV (for more details, see Chapter 3.3).



Rating scale: 1=Least concerned, 2=Slightly concerned, 3=Moderately concerned, 4=Very concerned, and 5=Most concerned.

Figure 15. Concern Ratings of AV between Urban and Rural Respondents

In addition, our survey results suggest that rural residents, in general, rated increased mobility for people with disabilities as the most beneficial prospect of implementing AV technology. Please see Chapter 3.4 of the supplemental version of the report for a more detailed analysis and results.

Regarding the effectiveness of education about AVs, we found that living in a rural setting negatively impacted the effectiveness of education about AVs. Older adults who live in proximity to a rural setting are less likely to have an increased rating of acceptance of AVs after education. It is corollary that they also reported lower rates of exposure to AV knowledge. The final SEM model reveals that "age" positively impacts the "rural setting," indicating that older generations are more likely to live in a rural setting instead of an urban setting. Living in a rural setting negatively impacts one's likelihood to experience AV technology, which is the leading contributor to people's acceptance of full automation vehicles (Level 5). Based on the modeling results, since people's acceptance of Level 5 automation positively predicts the effectiveness of AV education, living in a rural setting indirectly impacts the effectiveness of AV education. Please see Chapter 3.2 of the supplemental version of the report for a more detailed analysis and results on how the built environment (urban/rural setting) plays a role in influencing the effectiveness of AV education.

4.5 PWDs' Community in Accepting and Using AVs

In this research, we studied well-documented reporting from PWDs regarding acceptance and perceived benefits/concerns of future automated driving systems as well as the viewpoints on the same from the general public. Our statewide survey received ten responses from people with disabilities, who revealed that compared to non-PWDs, PWDs have a significantly higher AV acceptance and lower concerns about interacting with conventional vehicles, pedestrians, or cyclists on the road. Figures 16, 17, and 18 present the differences between PWDs and non-PWDs in accepting AV technology based on the collected public survey data.

Figure 16. Overall AV Acceptance between PWD and Non-PWD (Scale: -2~2)

Figure 17. Increase in Overall AV Acceptance between PWD and Non-PWD after AV Education? (Scale: -2~2)

Figure 18. Concern Rating of Interactive with Non-AV between PWD and Non-PWD (Scale: 1~5)

In addition, we found that people with disabilities are also more likely to adopt fully AV-based transportation services compared to non-PWD. It was suggested in the literature review that PWD would prefer to travel independently with anticipated AVs as a transformational travel solution (Darcy & Burke, 2018; Sundararajan et al., 2019). Our results supported this outlook; Figure 19 illustrates the significant differences between PWD and non-PWD in using AV-based transportation services. Please see Chapter 3.4 of the supplemental version of the report for a more detailed analysis and results.

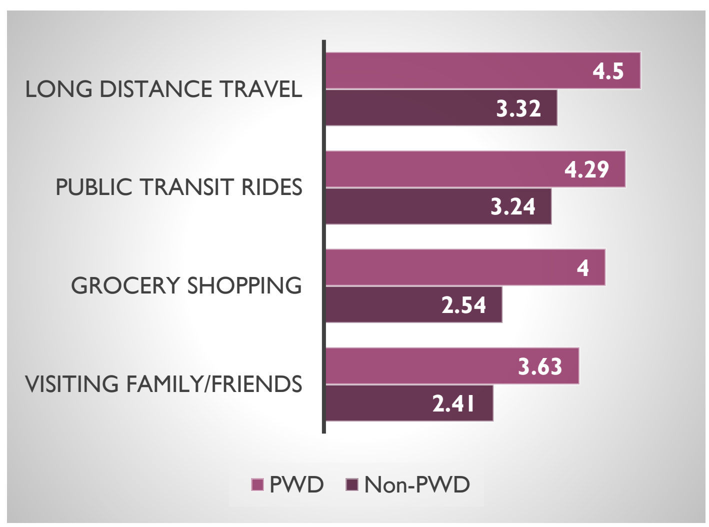


Figure 19. Preference Ratings in Using AV-based Transportation Services between PWD and Non-PWD.

For people without disabilities, an SEM method was applied to study the interrelationships among different factors that may affect people's attitudes and beliefs about the benefits of AV technology to the PWDs community. Age was revealed as a major predictor for people to support the benefits of AV to improve PWDs' mobility. It was further indicated that younger generations are more likely to support the benefits of AV to improve PWDs' mobility perhaps since they share some of the similar characteristics: residing in urban areas, with more frequent travel needs, higher level of education, and higher AV familiarity. On the other hand, our modeling results suggest that older adults are less likely to think that AV technology would benefit the PWDs community perhaps since more of them live in a rural setting with fewer travel needs and less exposure to AV. The SEM method points to associated travel patterns and affordability levels as crucial distinctions between people living in rural vs urban locations. Therefore, the pattern of travel needs and AV familiarity are the main factors seeming to influence people's support of adopting AV technology to solve mobility issues for PWDs. Moreover, the final SEM results suggest that people with a bachelor's degree or higher are significantly more likely to rate the benefit of adopting AV technology for PWDs higher compared to people who are less educated. Therefore, education, specifically having a bachelor's degree or higher, directly influences people's perceived benefit of using AV technology to improve PWDs' mobility issues. Although the factor of age appears to affect people's attitudes and beliefs about the benefits of AV technology for PWD, older adults (e.g., above the age of 60) who have higher-income levels (e.g., above $100,000 for annual household income) also tended to have higher ratings of the benefits that might improve PWD's mobility by using AVs. Please see Chapter 3.4 of the supplemental version of the final report for a more detailed analysis and results.

In addition to age and zip code, gender also appears to influence the benefit rating based on our modeling results. Our public survey data shows that women rated adoption of AV technology to support PWDs' mobility issues higher than their male counterparts. These survey respondents who selected the gender of "female" also tended to choose the highest education level of up to a graduate degree. In addition, survey respondents selecting the gender of "male" who chose a level of support for using AV to solve mobility issues also selected a high level of knowledge about AVs and selected having high travel needs. Please see Chapter 3.4 of the supplemental version of the final report for a more detailed analysis and results.

4.6 Kentuckians Try a Driving Simulator Programmed with ADAS and ADS

This research explored how human and machine factors influence AV driving safety at the different automation levels and how the safety performance of human drivers and machines differs at different automation levels. As illustrated in Figure 20, from the results of the driving simulator portion of our study, automated driving with a human driver behind the wheel outperforms fully human driving (Level 0) at all levels (Level 2, Level 3, and Level 4) for avoiding traffic conflicts and decreasing the severity of rear-end and angled conflicts (e.g., measured by more time to collision). In particular, Level 2 (partial automation) and Level 4 (high automation) results show consistently better performance compared to Level 3 (conditional automation) for avoiding traffic

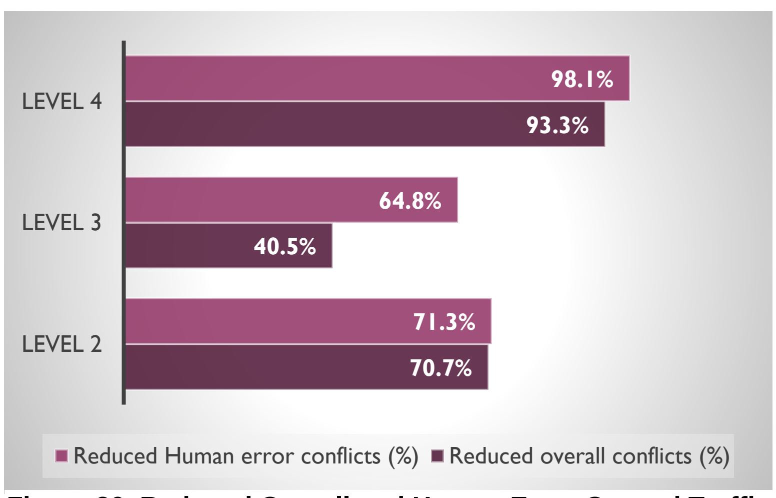


Figure 20. Reduced Overall and Human Error-Caused Traffic Conflicts under Levels 2, 3, 4

conflicts and reducing both the number of occurrences and severity of run-off the lane conflicts and angled conflicts. Between Level 2 and Level 4, Level 4 results showed consistently better performance in reducing the occurrences of angled conflicts. Overall, Level 4 results showed the most reduction in overall conflicts (93.3% reduction), followed by Level 2 (70.7%), and then Level 3 (40.5%).

In this experiment, the steering wheel, brake, and acceleration pedals remain under Levels 2, 3, and 4 automation. In the case of Level 2, a human is always in control of the environment. In the case of Levels 3 and 4, the human is only required to drive when summoned to do so but can take over the driving, regardless of whether he/she voluntarily takes over or is being requested to do so. In this case of human control, we investigated human error-related conflicts. Based on the collected driving data under different levels, Level 4 has the most overall human error-related conflicts reduction (98.1% reduction), followed by Level 2 (71.3%) and Level 3 (64.8%).

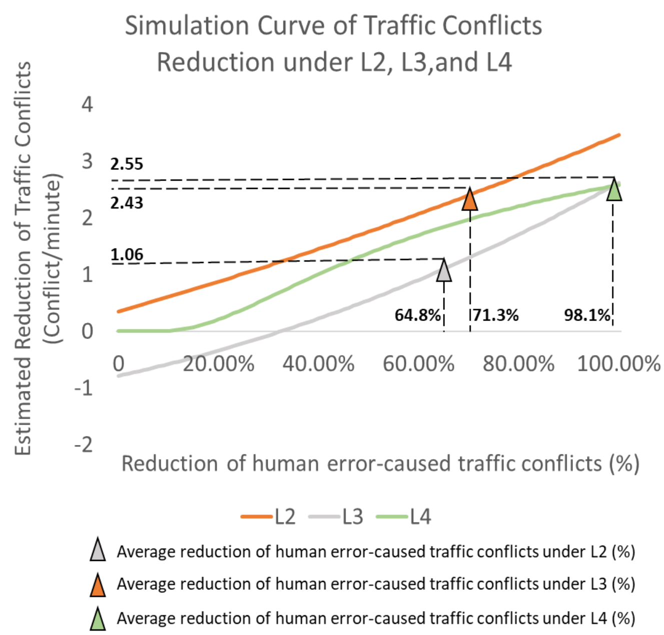


Figure 21. Simulation Curves of Traffic Conflicts Reduction under Level 2, Level 3, Level 4, and Validations

Inventors and developers claim that AV technology is supposed to improve driving safety by eliminating human errors. To test this claim, we predicted the improvement of safety performance under Levels 2, 3, and 4 systems by measuring reduced traffic conflicts per minute. From this data, we used two prediction model methods to estimate improved safety performance. Level 2 and Level 3 systems resulted in having R-square values above 0.35 and are significant at the 99% confidence interval, which means these models are highly reliable for predicting safety improvements if driving under Level 2 or Level 3. However, the prediction model for Level 4 did not achieve a good R-square value, even though we attempted to model it by conducting a mode-fit test to find out the form of the best fit model to describe the estimated safety improvement. This is a valuable outcome that can be used by researchers in the community of practice. For those, we recommend using these prediction models for Level 2 or Level 3 systems evaluation to estimate improved safety performance. These developed models can be validated

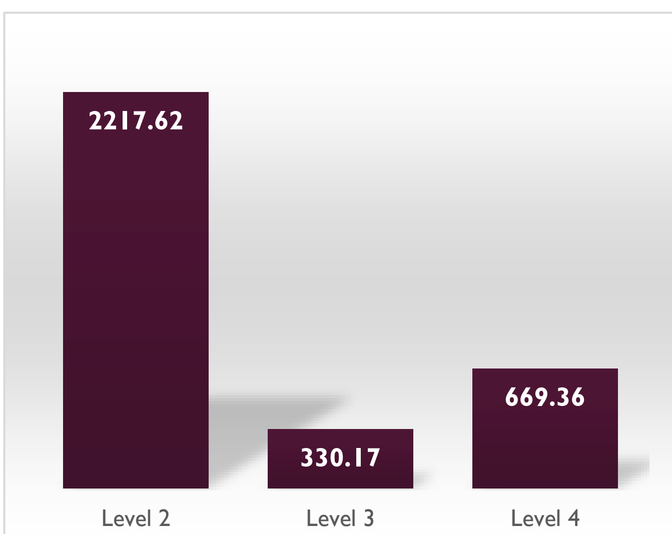


Figure 22. Benefit Cost (B/C) Ratio under Levels 2, 3, and 4

by comparing the ground truth data (collected from the simulator) and the simulated data in the form of average reduced conflicts by the minute. Figure 21 illustrates the simulation curves of estimating the reduction of traffic conflicts by reducing human error-related traffic conflicts at each 1% under Levels 2, 3, 4. Validation was also completed to ensure the simulation curve is valid in predicting the estimated reduction of traffic conflicts, also known as the enhanced safety benefits. We conclude that the ground truth and estimated average reduced traffic conflicts are similar, suggesting the validation of predicted models.

While Level 4 is considered the safest in our experiment, Level 4 also has more operational costs, such as increased travel delays due to strict speed limit adoption during the entire drive. Although AVs have the potential to improve driving safety, they might have the counter effect on operational efficiency because it is assumed that the travel speed under automated driving will be typically slower than under manual human driving. Hence, we investigated any trade-off we can detect between AV safety and operational efficiency. We found that a Level 4 system has the highest cost from increased delay if it is to strictly follow the speed limit during the entire drive. We also found that a Level 4 system can have the highest benefit from improved safety due to its ability to eliminate the largest number of conflicts caused by human errors. We employed the "benefit-cost ratio" (B/C ratio) to measure the ratio between safety and travel delay by converting them into costs. When considering both benefit and cost, Level 2 shows a significantly higher benefit-cost ratio than Level 3 and Level 4, as shown in the graph above in Figure 22.

Perhaps the most interesting outcome of this study is that we found that the driving behavioral performance of both machine and human-influenced people's attitudes about the perceived safety of AV and their acceptance. Our analysis showed that the more recorded reduced conflicts caused by human errors in the simulator data correlated with a higher rate of acceptance of the Level 4 automation system and the tendency of survey respondents choosing Level 4 as their favorite automation system.

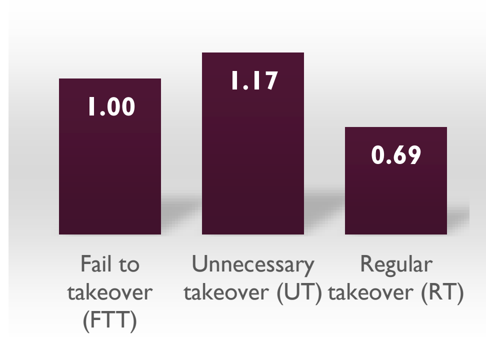


Figure 23. Traffic Conflicts per Type of Takeover Event

Three human driving behaviors were recorded in the experiment, namely "regular takeover (system requests human to takeover driving)," "fail to takeover (failure to respond to a takeover request

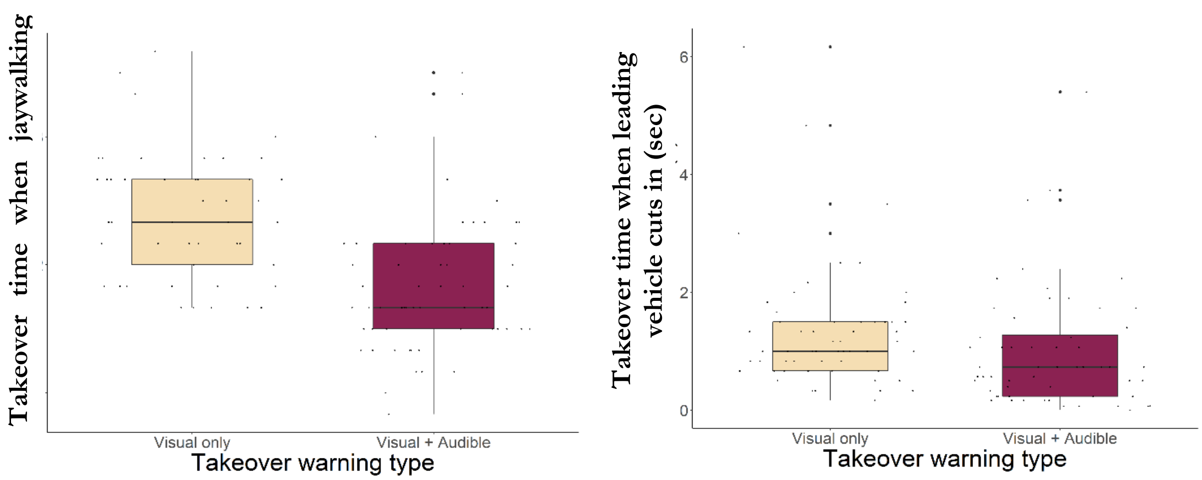


Figure 24. Takeover Time under Different Warning Types

from system),” and “unnecessary takeover (human driver engages without being requested by system).” We found that “regular takeover” causes a significantly lower number of conflicts per takeover event than “fail to takeover” and “unnecessary takeover.” “Fail to take over” has a similar impact on safety as an “unnecessary takeover” in terms of causing traffic conflicts. However, the “unnecessary takeover” leads to the highest severity in angled conflicts. Figure 23 presents the conflicts per takeover event under different driving behaviors.

In addition, warning message modality types could also influence risk reactions and the general acceptance of AV technology (Lee et al., 2020). Therefore, we measured the takeover time needed under Level 2 and Level 3 with different takeover warning types. We found that takeover time was significantly shortened under the “visual + audible” warning type compared to the “visual-only” warning type, regardless of the level of automation. Figure 24 illustrates the distribution of takeover time under different warning types in scenarios of “jaywalking” and “leading vehicle cutting-in”.

We also tested how different modes of takeover warning messages impact safety performances. We found that the “visual + audible” warning type under Level 3 effectively eliminates a significant number of conflicts per regular takeover event from 1.12 conflicts per takeover event to 0.08 conflicts per takeover event. The “visual + audible” warning type under Level 3 also significantly decreases the severity of angled conflicts compared to the “visual only” warning type by 16.4%. Figure 25 presents the traffic conflicts under each takeover warning mode.

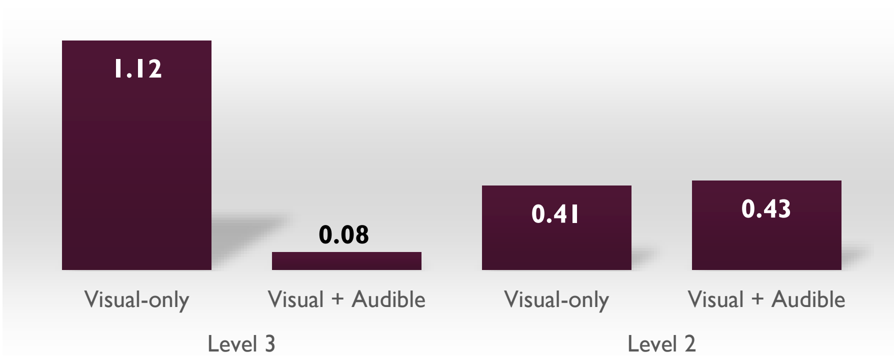


Figure 25. Conflicts Per Takeover by Levels and Warning Types

The above section summarizes all the key findings in AV driving safety. Please see Chapters 7 through 12 of the supplemental version of the final report for a more detailed analysis and results.

4.7 Effectiveness of AV Education Approaches

This report draws insights from the public survey and the driving simulator experiment combined with two forms of AV education carried out in this study. The first form of AV education was an introductory video that was viewed while participating in a public opinion survey, and the second form of AV education was a hands-on experience in automated driving via an AV driving simulator experiment. Volunteers in the simulator experiment also participated in the public survey opinion survey. We designed and embedded an informational introductive video on AV technology and relayed textual information into the public survey, and we also designed various levels of automated driving for participants who drove in the driving simulator experiment, hence having experiential education about AV technology.

Overall, participants reported feeling more positive about automated driving after viewing the informational video. When further experiencing the AV technology, however, through the driving simulator experiment, participants’ overall acceptance was significantly increased after having experienced simulated driving at Level 2 and Level 4 automation (as shown in figure 26).

Notably however, Level 3 automation, which expects a driver to respond appropriately to a request to intervene, did not solicit a high rating of acceptance. From these results, we determined that, while education increases familiarity with AV technology, leading to higher acceptance, user experience appears to be key for more impactful experiential education.

For the collected public survey responses, a Structural Equation Modeling (SEM) method of statistical analysis was used to study the interrelationships among different factors that impact the effectiveness of the information education module. It was observed that age has an impact on the effectiveness of the video-based education. In general, younger respondents were more comfortable with Level 5, full automation, while people's comfort rating with Level 5 appears to be the leading factor for increasing AV acceptance after education. Also, the modeling results showed that older respondents who had reported little previous knowledge about AV technology or respondents who selected a high affordability rate (high-income with a bachelor's degree or above) were more likely to show increases in AV acceptance after watching the informational video. Besides age, gender also played a role statistically in predicting the effectiveness of AV education. Our results revealed that women were more likely to find the AV education video effective in enhancing their AV acceptance. By investigating further, we found AV familiarity mediated the path from gender to AV acceptance. More specifically, women were more likely to find the AV education video effective due to a generally lower AV familiarity response compared to men. Thus, education appears to be the most effective for people who previously have relatively low AV familiarity and higher affordability levels. Please see Chapter 3.2 in the supplemental report for a more detailed analysis and results regarding AV education through watching the video.

For the driving simulator experiment, an SEM method of statistical analysis was used to study the interrelationships among different factors that impact the effectiveness of the experiential educational driving of an AV. It was observed that the simulated automated driving experience was particularly effective for people 50 years of age or above, whose annual household income is above $30,000, and for people with a lower education level (e.g., less than a bachelor's degree). The effectiveness of increasing acceptance of AVs in this experiential driving education appears the most likely when the participants' age increases. Since each participant drove the driving simulator under Levels 0, 2, 3, and 4, we also identified how different levels of automation influenced the effectiveness of the driving experiences. Among the three levels with some degree of automation, experience after driving Level 2 (partial automation) and Level 4 (high automation) significantly increased people's overall acceptance of AV technology and purchase intentions, as illustrated in Figure 26. However, the experience of simulating Level 3 driving (conditional automation) had the least positive impact on the overall acceptance of AV technology and purchase intentions. In general, after simulated driving at Level 4, perceived safety for AV technology increased, which is the main attributor for the overall increased AV acceptance and purchase intention of AV.

Similarly, after simulated driving with Level 2, partial automation, the post-driving survey results showed that participants had fewer safety concerns for AV technology and a reduced concern about taking over driving. However, after simulated driving with Level 3, conditional automation, participants had more concern about the transition from automated to manual driving. An SEM method of statistical analysis suggests that their overall acceptance after driving with Level 3 automation was positively correlated with income but negatively correlated with education level. Thus, people with higher education levels were generally more concerned about the taking-over process. Please see Chapter 6 and Chapter 13 in the supplemental report for more detailed analysis and results regarding AV education through experiencing automated driving.

Finally, we evaluated the two AV education methods and their effectiveness in increasing overall AV acceptance. In terms of watching the video, respondents became significantly more positive about automated driving after education than before education. Their AV acceptance was increased from 0.47 to 0.87 on a -2 (very negative) to 2 (very positive) scale. Urban respondents had an increased overall AV acceptance after watching the video compared to rural respondents. Their AV acceptance was increased from 0.63 to 1.068 on a -2 (very negative) to 2 (very positive) scale. For participants who participated in the AV driving simulator study, their overall acceptance rating was significantly increased after participants test drove a simulation at Level 2 (from 0.85 to 1.10) and at Level 4 automation (from 0.85 to 1.38), but acceptance rankings were significantly lower after they test drove a Level 3 automation in the simulator (from 0.85 to 0.22). Underlying reasons for increasing overall acceptance after the test drive at Level 4 are: (1) increased benefit levels of Level 4 safety and (2) increased benefit levels of the driving freedom of Level 4. The reason that led to the decrease of overall acceptance after a simulated drive at Level 3 is the concern of taking over. Finally, underlying reasons for increasing the overall acceptance after a simulated drive at Level 2 are: (1) reduced concern of Level 2 safety and (2) reduced concern of taking over under Level 2.

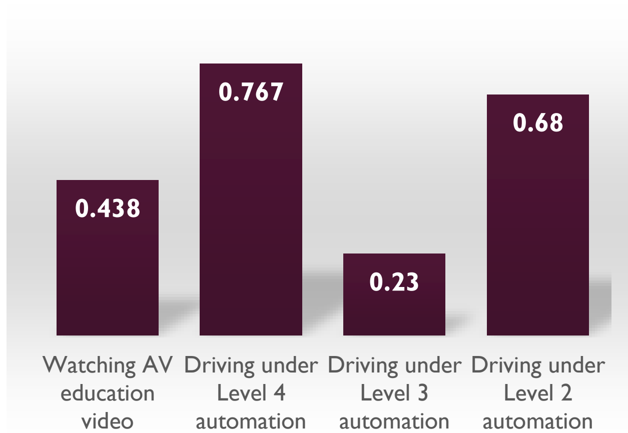


Figure 26. Increasing Acceptance Ratings Test after Both Video and Hands-On AV Education Approaches (Scale -2~2).

We also compared these two AV education methods in terms of effectiveness in increasing AV acceptance (Figure 26). As a result, by experiencing AV driving of either Level 2 or Level 4 automation, the acceptance ratings were higher by 0.242 to 0.329, respectively, than they were after watching the AV introduction video only. Please see Chapter 14 of the supplemental version of the final report for a more detailed analysis and results.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Acceptance of AVs

As a result of our study, we found that a majority of Kentucky residents showed a supportive and welcoming view of AV technology; over half of those surveyed reported feeling positive toward AVs. People living in urban settings tended to have a higher acceptance of AVs compared to people living in rural settings by a margin of 0.48. Urban drivers tended to feel more comfortable driving under automation Levels 2, 3, 4, and 5 compared to rural drivers by a margin of 0.52, 0.51, 0.62, and 0.71, respectively.

When we assessed Kentucky residents' responses to questions asking what concerns they have about AVs and what potential benefits they think AVs will have, we found that most Kentucky residents chose AV safety (in terms of equipment failure or system failure) as their number one concern and chose "enhanced driving safety" as the number one potential benefit.

We also asked questions to assess how Kentuckians felt about using AV technology for their commute to work. When asked if they would consider living farther from work if automated driving were available, drivers' opinions varied depending on the level of driving automation. Our study found that a bigger proportion of Kentucky drivers are more likely to live farther from work if full automation were available, compared to a smaller proportion of drivers who would choose to live farther from work if driving under partial automation.

This research also looked at how age and gender affect overall acceptance of AV technology and the different levels of driving automation. In general, men reported having greater familiarity with AV technology, which corresponded with higher levels of acceptance. Regarding age, younger respondents were generally more open to the use of AV technology, especially at Level 5, full automation.

The results of this research are intended to inform readers about the opinions of Kentucky residents toward AV technology. Legislators, policymakers, and transportation officials may also find this information valuable when considering any future decisions related to AVs, especially our findings that education increased favorability ratings toward AVs. Both methods of education—an informational video and simulated driving—increased participants' positive ratings across age, gender, and the built environment (urban/rural setting), to larger and lesser degrees.

From the Kentucky drivers' perspective, people who experience hands-on simulated driving of AVs gained experience along with trust or distrust of the various systems. As automated driving systems mature and demonstrate safety benefits such as those shown in the perfect world of simulation, perhaps people will experience and trust the systems in the same way. From the perspective of legislators, if policymakers or legislators choose to promote ADS in Kentucky, then the idea of promotion through media campaigns might be considered, as media campaigns can be a very effective way to get information out to the general public about this potential and life-saving technology. This study identified differences in accepting AV between people from urban and rural settings and found that ADASs available today are less desirable in rural areas. In Kentucky, where run-off-the-road crashes are a major concern, especially in rural areas, this presents an opportunity for manufacturers to do more education about ADAS. Moreover, government agencies can cooperate with local Vehicle Licensing as well as non-profit organizations, such as Partners for Automated Vehicle Education (PAVE), to educate drivers by adding automated driving-related components in the driver's license training or renewal program.

5.2 Affordability of AVs

As part of assessing the acceptance of AV technology by Kentucky residents, we evaluated their willingness-to-purchase, finding seven out of 10 respondents would consider purchasing an AV when available. In this evaluation, we found a correlation between respondents having a higher rating of willingness to purchase and AV safety, driving freedom, environmental friendliness, and a desire for increasing mobility levels for people with disabilities. In contrast, the concerns of AVs included the absence of human control in the vehicle, data privacy, interacting with non-AVs on the road, and take-over driving (as described in Figure 23); these factors correlated with respondents' lower ratings of willingness to purchase.

When we evaluated how much extra money respondents would be willing to spend on AV technology, we assessed the Kentucky drivers' affordability in purchasing Levels 2, 3, 4, and 5. The average amount of money a respondent was willing to spend was $5,954, $7,517, $9,116, and $10,712, respectively.

However, a follow-up question was asked for those who would not consider purchasing an AV. When asked if price was the biggest concern, only 17% of respondents said yes. This finding suggests that the cost is not a top priority in determining the willingness to purchase. Instead, AV policymakers can benefit from this finding by comprehensively understanding the driving force for the general public in purchasing an AV in the future. Specifically, AV's identified potential benefits and concerns in significantly impacting the willingness-to-purchase of an AV can contribute to policymakers. Particularly, based on the identified concerns of AV, potential education programs can be provided in removing the barriers that prevent the general public from purchasing an AV.

5.3 Preference in Using AV-Based Transportation Services

Our survey asked respondents about their preferences in using AV-based transportation services under multiple circumstances. We found the top three most preferred scenarios to be: a ride after consuming alcohol, airport shuttle, and long-distance travel. The least preferred use is a church visit. More urbanized areas reflect a higher preference rating using AV-based transportation services. Age, gender, affordability level, and exposure levels to AV technology were identified as having significant impacts on that preference rating. Moreover, when asked the specific level of automation preferred in these scenarios, 58% of Kentucky residents support the statement of expecting Level 5, or full automation, to serve people who need transportation who would otherwise drive impaired. Kentucky drivers who reported having a higher familiarity of AV or comfortableness with high automation, or having a bachelor's degree or above, tended to be willing to serve as a "safety driver" in an automated TNC (e.g., Uber/Lyft) operating under high automation.

Since "a ride after consuming alcohol" has been identified as one of the most preferred AV-based transportation services by Kentucky drivers, future studies can be carried out in terms of determining the specific thresholds of alcohol for different levels of automation in serving driving-impaired people. For example, what is an estimated range of alcohol concentration that driving-impaired people can ride a vehicle that operates under Level 4? Should a vehicle operating under Level 5 automation have human control or not? The answers to these questions can be helpful for policymakers in shaping a path forward for the possibility of addressing the safety issues due to driving-impaired people in the future.

However, we notice that survey respondents who actually rely on public transportation did not show higher preferences in AV-based transportation services. In reality, AV is expected to provide safer and more cost-effective transportation for people with lower incomes, especially older people with lower incomes and those living in rural settings, therefore benefitting these residents. Our data suggested that this discrepancy is largely due to the lower levels of comfortableness with full driving automation, which is perhaps because of fear or unfamiliarity. Therefore, we recommend providing public AV education via social media, TV, and radio to raise the awareness of AV safety, increase familiarity and remove the fear of full AVs with people who have lower income levels or are living in rural communities. Education with these residents would increase their trust in the technology and ultimately provide the benefits of full AV transportation services in the long run.

5.4 AV Implementation in Rural Communities

As summarized above, we found a distinction between urban and rural respondents when it came to acceptance, willingness-to-purchase, preference ratings in using AV-based transportation services, and the effectiveness of AV education. In brief, compared to urban residents, rural residents have lower acceptance levels to AV (urban vs. rural: 1.69 vs. 1.24, on a scale from -2 to 2), less intention to pay for AV (urban vs. rural: 74.8% vs. 58.7% in terms of probability of purchasing), and less enthusiasm to use AV-based transportation services (urban vs. rural: 3.13 vs. 2.66, on a scale from 1 to 5). Moreover, video-based education was also less effective for rural residents in enhancing their AV acceptance (urban vs. rural: 48% vs. 36% in terms of probability of AV acceptance being increased).

With AV technology being recognized as a game-changer in the transportation system (Emberger & Pfaffenbichler, 2020), many benefits such as reducing crashes due to human errors, reducing congestion, and reducing transportation emissions can be achieved if AV is implemented properly (Compostella et al., 2021; Winter et al., 2021). However, lacking basic knowledge and exposure to AVs, the general public shows skepticism and mistrust toward AV technology (PAVE, 2020). AVs' anticipated benefits will not be realized if AVs are not widely accepted, adopted, and used in our daily lives. In order to facilitate the implementation of AV in rural areas, an additional AV education approach, such as real experience in riding in an AV, could be carried out. Demonstrations of personal AVs or Automated Shuttles can be conducted in rural areas. As introduced in this study, rural residents were mostly concerned with riding in a vehicle with no driver controls, followed by safety consequences of equipment/system failure, and AVs being more expensive than the conventional vehicle. Therefore, during demonstrations, specific education to address these concerns can be conducted. For example, coordinators who are on-site for these activities can explain that the automated shuttles currently under operations have “safety drivers” on standby, responsible for handling emergencies such as automated driving system malfunction. Hence, more efforts are needed to educate rural residents regarding AV and better accept, adopt, and use AV-based transportation services.

5.5 AV Implementation in PWDs Communities

Based on previous research and our study findings, people with disabilities embrace the implementation of AV technology to improve their mobility. They generally have higher overall AV acceptance than the general public. The AV education programs were also more effective in improving their overall AV acceptance. Therefore, AV policymakers can start with identifying the potential hotspots (e.g., senior living apartments) that need AV services from perspectives such as grocery shopping, medical visits, and recreations. Targeting the PWD community with various education and outreach programs is recommended before the implementation of AV services because PWD are more receptive to receiving education on automated driving compared to those who do not have disabilities. More specifically, our study indicated several key transportation needs for the PWD community: friends and family visits, grocery shopping, long-distance travel, and public transit. Therefore, AV-operated shuttles to grocery stores and parks and AV-operated car rentals for short and long-distance personal use are recommended AV services for PWD communities due to the significantly higher preferences. Because an increasing number of PWD may use these public transit areas when AV transportation services are provided, public transit infrastructure development should consider PWD’s travel needs, such as expanding the waiting areas for wheelchairs. In addition to AV services specifically targeting PWD communities, to meet PWD's diverse travel needs, we suggest state and federal transportation agencies be prepared for the potential changes in future travel behaviors of PWD if AV is fully implemented.

From the general public’s perspective, respondents in our survey show overall supportive views on improving PWD’s mobility issues using AV. In general, AV acceptance plays an essential role in determining the perceived benefit of using automated driving to improve PWDs' mobility. However, the built environment, such as living in a rural setting, is the biggest challenge hindering the general support from the public. The "rural setting" reduces the probability of showing a higher benefit rating from automated driving in improving PWDs' mobility by 14.7%. Based on the aforementioned conclusions, we suggest using urbanized areas as the pilot focus to implement AV-based transportation services for PWDs, which may be easier to begin the early-stage implementation. Furthermore, communities with residents having the following traits can be considered as priorities to pilot the implementation: (1) younger adults with higher education levels, travel needs, affordability levels, and exposure levels to AV; (2) women with higher education levels; and (3) men with higher AV exposure levels, travel needs, and affordability levels.

Although it might be easier to start implementing AV services from the urban areas, persistent education efforts designed to target older generations living in rural areas are crucial to improve their familiarity and finally overall acceptance to better service every Kentucky resident and their variety of needs.

5.6 AV Safety

Automated driving has the potential of enhancing driving safety by eliminating human errors. This study confirms this statement in a simulated environment. In general, our results show driving under Levels 2, 3, or 4 successfully reduces the traffic conflicts caused by human drivers, with Level 4 having the largest reduction. Moreover, this study evaluated the safety performance for automation at different levels. In general, our results show driving under Level 2, Level 3, or Level 4 is safer than manual driving (Level 0). Level 4 is considered as safe as Level 2, and both provide more safety improvements than Level 3.

In terms of warning message modalities, we found that a "visual + audible" warning type is more effective in guiding drivers to take over the driving, which significantly reduced the amount of reaction time versus the "visual-only" type of warning. In addition, we found that the "visual + audible" warning type under Level 3 automated driving can significantly improve driving safety. In terms of different driving behaviors, our analysis showed that regular takeover (system requests human to takeover driving) outperformed failure to takeover (failure to respond to a takeover request from system) and unnecessary takeover (human driver engages without being requested by system) for driving safety. Regarding the trade-off between AV safety and operational efficiency, Level 2 driving automation has a significantly higher benefit-cost ratio compared to Level 3 and Level 4 automation.

This study also confirms the ambiguity of Level 3 in terms of its definition and safety concerns, thus policymakers or decision-makers on AV safety could focus on the potential safety hazards from Level 3. In terms of effectiveness of the models used, both prediction models of estimating safety improvements by Level 2 and Level 3 suggest strong prediction ability, whereas the prediction model for Level 4 did not achieve a good model fit regardless of our multi-approach attempts. Therefore, it is recommended to use the prediction models for Level 2 or Level 3 to estimate safety improvements with confidence and use the Level 4 model with caution.

We recommend using predictive models to estimate how much safety improvements (e.g., reduction in traffic conflicts) can be achieved when implementing different levels of automation. In addition, reduction in human error can be used as a predictor to further assess the safety improvement under automated driving.

5.7 Education on Automated Driving

As part of assessing Kentucky drivers' acceptance of AVs two educational approaches on automated driving were practiced to both introduce the technology to Kentucky residents and gauge their current and previous understanding of AVs. These two educational approaches were watching an introduction video and a more hands-on approach of experiencing driving of an AV in a driving simulator.

For Kentucky residents who received the AV education via watching the AV introduction video when participating in the public survey, we found that the video was more effective for the focus groups with the following traits based on their overall enhanced AV acceptance after viewing the video: (1) younger adults with higher levels of comfortableness with full driving automation, with experience of riding/driving an AV, and living in urban settings; (2) older adults who know little about AV technology but have higher affordability levels and live in urban settings; and (3) women who know little about AV technology. Based on the aforementioned conclusions, people's exposure to AV technology plays an important role in determining the effectiveness of the AV educational video. For those who have little knowledge of AV technology, we recommend a two-phase AV education plan. First, an AV educational video can increase awareness of the basics of AV technology. Second, the experience of riding in an AV simulator can replicate the actual experience, aiming to address psychological issues such as fear and mistrust. For those who already have higher exposure to AV technology, such as people in urbanized areas, we recommend the experience of riding in an actual AV (automated shuttle) perhaps through regularly scheduling demonstrations. Potential locations can be on campuses, senior living communities, airports, and grocery stores. Automated Shuttle demonstrations in some of the biggest public events in Kentucky such as the Kentucky State Fair, Kentucky Derby, or Thunder Over Louisville may also provide greater public exposure.

For Kentucky residents who participated in driving the AV simulator, the hands-on AV education is more effective for the people having the following traits: (1) older than 50 years or above; (2) having an annual household income above $30K; and (3) those who do not have a bachelor's degree. Based on the aforementioned findings, we found that younger, lower-income, and highly educated drivers are less likely to increase their overall AV acceptance after experiencing the hands-on AV driving, potentially due to their already high acceptance level to AV or a low interest in AV technology. In this case, we suggest focusing on the aforementioned focus groups with practicing hands-on AV education.

Finally, when comparing the two AV education methods' effectiveness, we found that simulated driving under high automation (Level 4) has the largest increase in overall AV acceptance, followed by simulated driving under partial automation (Level 2) paired with watching the AV education video. Driving under conditional automation (Level 3) has the least increase in overall AV acceptance, perhaps due to the ambiguity of the definition of conditional automation and the safety concern. The finding mentioned above is consistent with what we concluded in Section 5.6, AV Safety. Therefore, we recommend using the vehicles operating under partial or high automation when practicing hands-on AV education and using the vehicles operating under conditional automation with caution.

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