User Experience and Analysis of an Autonomous Shuttle Service

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Abstract: As the use of autonomous vehicles for public transportation becomes more prevalent, it is important to examine characteristics of potential users and their perception of the service. This study aimed to capture user opinions and feedback from both riders and non-riders concerning an autonomous shuttle service. Potential differences in user groups were examined as well, comparing employees of the Department of Defense to civilian users. Participants generally held positive opinions about the shuttle, although riders were more likely to rate the service favourably. Civilian users were also more likely to rate the shuttle favourably and more often claimed that they would recommend it to others. The youngest participants tended to report higher levels of agreement and acceptance on perceived safety and intelligence as well as the shuttle's avoidance of obstacles and obedience of traffic rules. Research in this area has implications for all facets of the transportation industry as well as future users of autonomous public transportation.

1 INTRODUCTION

The Society of Automotive Engineers International defines Driving Automation Systems as motor vehicle driving automation systems that perform part or all of the dynamic driving task on a sustained basis, with further classifications for six levels of driving automation, ranging from no driving automation (Level 0) to full driving automation (Level 5) (SAE International, 2018). Colloquially, "autonomous" or "driverless" has been used to describe the major feature of the Level 5 driving automation systems - vehicles that can drive without human control (Ruijten, 2018). Over the past several years, there has been a push for the development and use of autonomous vehicles (AV). A major motivator for this has been the potential for increased roadway safety. In 2015, the US National Highway Traffic Safety Administration found that in 94% of automobile crashes, fault was assigned to the driver, meaning that human error played a role in the accident. In their examination, these critical reasons were classified into recognition errors, decision errors, performance errors, and non-performance errors (Singh, 2015). AVs have the potential to mitigate various types of human errors in driving and could play a significant role in accident reduction on the roadways. With full implementation of AVs, it is predicted that accidents could be reduced by up to 90%, which, in turn, could potentially save up to $190 billion in the healthcare costs that are associated with these accidents (Bertoncello & Wee, 2015). Besides safety, AV technology is also able to provide mobility for non-drivers such as the young, the elderly, and people with physical disabilities (Alkan, 2017).

Other recent research has focused on the benefits of autonomous public transportation. One example of this is autonomous shuttles (AS) or buses (AB). Like autonomous personal vehicles, safety plays an important role in the design and implementation of AS. They also operate in environments where unpredictable situations are inevitable, such as interactions with pedestrians, intersections without traffic lights, and roundabouts (Wang et al., 2018).

Passenger acceptance and willingness to ride the AS should be considered in the design and implementation of these shuttles. There are three key factors that have been shown to determine passengers' acceptance of AS: safety, comfort, and convenience (Eden et al., 2017). A study by Dong et al. (2017) on an AB service in Philadelphia gave further insight into passenger acceptance. Of the 891

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surveyed riders, two-thirds were willing to ride in an AB when a transit employee, who could perform take over requests, was also on board. Only 13% of those surveyed would agree to ride in the bus in the absence of a transit employee. In addition, those under the age of 45 years were more willing to ride in an AB – possibly due to greater exposure to various digital features and automated technology in this age group. These results show optimism for an increase in acceptance of automated technologies as younger generations grow with the advancement of automated technologies and along with it bring less scepticism (Dong et al., 2017). In line with these results, the Mcity research project conducted at the University of Michigan found that riders were more likely than non-riders (86% vs. 66%) to report trust in an AS service (Kolodge et al., 2020). These findings further emphasize the idea that exposure to technology may have an effect on acceptance of technological advancements.

In the past decade, there have been major shifts in the public transportation market. With these shifts, there has been a significant increase in the use of app-based transportation services. For example, within the past five years, the ridesharing industry has greatly increased its share in the transportation market due to easy accessibility and convenience. In 2016, ridesharing apps such as Uber and Lyft surpassed taxis in New York City for total number of pickups (Wagner et al., 2018). A fairly recent implementation within this ridesharing industry has been the use of AVs. Starting in 2015, Uber started testing AVs in Pittsburgh, Phoenix, and Toronto. Along with AV Ubers and AV shuttles, driverless taxis have recently been tested in Japan in 2018. The trial lasted roughly one month and took place on a 5.3 km route that was mapped out. In all, around 1,500 people applied to be passengers in this study (Chowdhury, 2018).

Another major factor that plays a role in a person's acceptance is comfort. As AS becomes more prominent, it is also important to design the shuttles in a way that is comfortable for all passengers. The layout of seating on public transportation plays a role in the social comfort of passengers (Thomas, 2009). Seating layouts that force passengers into close proximity with strangers can lead to social discomfort (Thomas, 2009). In a ridesharing context, seating impacts both passengers' privacy and comfort (Ong et al., 2019). The lack of passengers' privacy and comfort during rides is further exacerbated when in the presence of others; this could be dependent on whether the riders are familiar with each other. For instance, a study investigated social interactions on railway transit and found that people who were familiar with one another, such as friends, were less reserved and interacted more (Bissell, 2010). Those who are sharing rides with familiar people, such as friends or regulars, may be less bound by the social tension that is created through a close quarters seating layout. Additionally, seat availability and design may serve to influence general comfort. Seats with clearly defined boundaries and separation from others are more ideal to passengers (Lombardi & Ciceri, 2019).

Most user acceptance studies in the context of AVs to date focused on passenger cars, little has been done to look at the perceptions people have of larger AVs such as shuttles. The current research focuses specifically on perceptions of an AS service and the likelihood to recommend this mode of transportation. This study is a secondary data analysis on an AS feasibility study conducted at a military base. Details of the study can be found in Allen et al. (2020).

2 METHODOLOGY

2.1 Description of the Autonomous Shuttles

The dimensions of the exterior of the AS are 12.86 feet by 6.73 feet with a height of 8.20 feet. The wheelbase of the vehicle extends to 8.29 feet. The interior height reaches 6.40 feet. Each AS can carry up to 1,350 pounds, an estimated maximum of twelve passengers, but only eight seats are present in this model of AS. This passenger limit must also include the safety operator. The AS can travel an average distance of 40 miles at nominal conditions, and 25 miles if operating with the maximum load and maximum air conditioning. The maximum speed is 25 mph and one and a half hours is required to reach a full charge. The AS was programmed to operate on a defined route at the military base, and a safety operator was required to be present during all operations and to take-over manual control of the AS if necessary.

2.2 Study Procedures and Data Collection

This research consisted of two phases: a pilot, invitational phase (during July 2019) and a main study (from late August to end of September 2019).

2.2.1 Pilot Study

During the pilot phase, the study team invited individuals who worked on- and off-base (including officials from other Department of Defense (DoD) and Federal agencies as well as organizations in the local area) to either observe the operations of the AS or ride the AS. This study received Institutional Research Board approval from the authors' university and US Army Engineer Research and Development Center's Construction Engineering Research Laboratory. Upon experiencing the AS (either as a rider or a non-rider observer), participants were asked to complete either a paper version of the survey (on-site) immediately or an electronic version of the survey administered by the AS company (on-line) within a few days. It took approximately five minutes to complete the survey.

Of the 47 valid responses, all participants were passengers who had ridden the shuttle either one or two times. The mean age of this data set was 44.4 years (*SD* = 11.29). No other demographic information was collected. A fourth of participants (25.53%) lived or worked on the base; 10.64% of participants worked for the DoD but did not live on base, while the remainder (63.83%) of participants did not work for the DoD. Participants received their information about the shuttle primarily from the onboard safety operators (91.48%), while some participants heard from media (14.89%), word of mouth (4.26%), and information operator publications (4.26%). Three participants received no information before their ride (6.38%).

2.2.2 Main Study

The study team welcomed anyone who worked on- and off-base to experience the AS, which operated during a two-hour lunch period. Through advertisements, personnel who worked or lived on-base, visitors to the base, and individuals who heard about the AS could ride the AS and consent to participate in the main study. This study received Institutional Research Board approval from the authors' university and US Army Engineer Research and Development Center's Construction Engineering Research Laboratory. Upon experiencing the AS (either as a rider or a non-rider observer), participants were asked to complete either a paper version of the survey (on-site) immediately or an electronic version of the survey administered by the AS company (on-line) within a few days. It took approximately five minutes to complete the survey. A total of 21 questions were included in the survey: most of the items were identical to those used during the pilot study, but some adjustments and additions were deemed necessary to capture the demographics of the riders and non-riders during the main study. For example, one question asked for participants' normal mode of travel on base and another asked for the likelihood of recommending this service to others. The same Likert-scale questions were included, with the comfort rating being divided into two questions; the first for riders and the second for non-rider observers. An additional Likert-scale question asked for the perceived value of the AS operating on the base. The survey then asked if the riders would use the service again. Participants were able to give open-ended feedback at two points during the survey.

Participants who reported interacting with the AS as a safety operator and those listed as "Other" were removed from data analysis (*n* = 5). Participants who had taken the survey multiple times were also removed (*n* = 3). Of the remaining 98 valid responses, 67 were passengers (31 were non-rider observers). The mean age of this data set was 37.71 years (*SD* = 14.85). The mean age for passengers was 40.62 years (*SD* = 14.04) and the mean age for non-rider observers was 31.40 years (*SD* = 14.82). No other demographic information was collected. About half (49.47%) of participants worked for the DoD. Almost half of the participants travelled around the base in a personal vehicle (47.96%), while the next largest group walked (17.35%). The majority of participants had been a passenger on the shuttle one to two times (68.37%).

2.3 Simple Correspondence Analysis

Simple Correspondence Analysis (SCA) is an exploratory method for visualizing contingency tables on graphs and trends in the data (Clausen, 1998). The only assumption of SCA is that the values are non-negative. In addition, outliers defined as one standard deviation away from the centroid (origin) were removed because they compress the SCA plots and make interpretation difficult (Bendixen, 2003). The units on the plots are standard deviations from the centroid.

SCA was used to visualize participants' perception of the AS service and technology across three age groups. The six variables about the AS service and technology were: Perceived Intelligence, Regular Use of Shuttle, Perceived Safety, Perceived Trustworthiness, Avoidance of Obstacles, and Obedience of Traffic Rules. Participants rated their level of agreement (strongly disagree to strongly agree) for the first four variables and level of acceptance (totally unacceptance to perfectly acceptance) for the last two variables. Age was collected as a continuous variable but for the purposes of SCA, it was binned to have equal N across groups.

Initially, we hypothesized that three age groups (two dimensions) would be appropriate. After reviewing the inflection point of the scree plots and eigenvalues (variance) produced by the correspondence analysis, three age groups (two dimensions) were deemed appropriate for the analysis (Kassambara, 2017). The age groups were 20-40, 41-51, and 52-61 for the pilot study and 19-27, 28-45, and 46-70 for the main study. Twelve contingency tables were analysed using SCA (six variables of interest per study). The pilot study had one participant removed for missing age values; the main study had two removed. Data analysis was conducted in R v.3.6.2 using FactoMineR and factoextra packages (Le et al. 2008; Kassambara & Mundt, 2020).

3 RESULTS

3.1 Pilot Study Results

The participants in the pilot study agreed that the shuttle was intelligent (18.3%), safe (17.0%), trustworthy (15.0%), comfortable (15.0%), and that it would be used regularly (17.0%). Participants also rated the shuttle as acceptable at following traffic rules (12.4%) and avoiding obstacles such as pedestrians and other vehicles (18.3%). A Chi-Square test showed a significant association between age and rating of Perceived Safety. $\chi^2(6, N = 47) = 16.20, p = .013$. Everyone responded either "neither agree nor disagree" or higher to the statement "The Vehicle is Safe." Those in the youngest age group (20-40) responded "strongly agree" more than those in the 41-51 and 52-61 age groups.

Results from the SCA indicated that, overall, participants in the pilot study had a favourable view of the AS service and technology. In five out of the six variables of interest, participants reported acceptability of at least neutral or higher. The SCA plots are presented in the Appendix. SCA indicates which groups have similar frequency counts (red for the survey response and blue for age groups) and therefore describes general grouping patterns (Kassambara, 2017). Percent of variance explained by the dimensions is presented in Table 1. Of note, two outliers were found in the Avoidance of Obstacles variable (slightly unacceptable, $n = 44$) as well as one outlier in the Perceived Safety variable (neither agree nor disagree, $n = 45$).

When looking at the Perceived Intelligence plot, it was interesting to note that both older age groups clustered closely around "strongly agree" and "agree," respectively. However, for the Regular Use of Shuttle variable, both 20-40 and 52-61 age groups were grouped around "agree" indicating similar frequency responses. The youngest age group responded the most frequently with "strongly agree" to the Perceived Safety variable. For Perceived Trustworthiness, individuals aged 52-61 had similar response frequencies with "neither agree nor disagree" as well as "agree" while individuals 41-51 grouped more closely with "somewhat agree." Avoidance of Obstacles showed that the youngest age group (20-40) mostly reported "acceptable." For the Obedience of Traffic Rules variable, individuals aged 41-51 were grouped with "slightly acceptable" and "perfectly acceptable" while those aged 20-40 grouped closer to "acceptable."

Table 1: Variance (%) Explained by Dimension 1 and 2 – Pilot Study.

Variable	Variance in Dimension 1	Variance in Dimension 2
Perceived Intelligence	71.15	28.85
Regular use of Shuttle	97.05	2.95
Perceived Safety	97.58	2.42
Perceived Trustworthiness	98.35	1.65
Avoidance of Obstacles	89.53	10.47
Obedience of Traffic Rules	92.25	7.75

3.2 Main Study Results

The passengers in the main study reported that the most common reason for riding was curiosity, at 29.5%. The next most reported reason was for research (25.7%), followed by convenience (8.6%). Only two participants were interested in accessibility (1.9%) and 13 participants listed multiple reasons for riding the shuttle.

Participants who worked for the DoD rated the AS negatively more often than their counterparts for the perceived value to the base ($U = 673.00, p = .024$). Those who did not work for the DoD stated that they would be more likely to recommend the AS to a friend ($U = 469.00, p < .001$) (Figure 1). When comparing riders to non-riders, riders rated the AS favourably more often on many variables including Perceived Safety, Perceived Trustworthiness, and the value of the shuttle to the base (Table 2).

A Chi-Square Test showed no significant association between the typical method of transportation around the base and DoD employment, $\chi^2(4, N = 77) = 4.16, p = 0.38$.

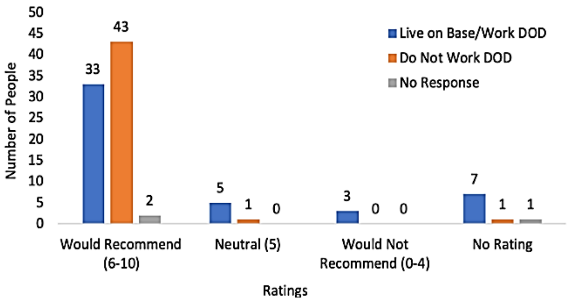

Figure 1: Distribution of Recommendation Ratings Across DoD and non-DoD Participants.

Table 2: Riders vs Non-Rider Ratings of AS – Main Study.

	Riders		Non-Riders				
	Mean Rank	*n*	Mean Rank	*n*	*U*	*z*	*p*
Recommend to Others	52.47	64	20.43	23	194.00	-5.40	0.000
Perceived Value on Base	49.54	61	33.11	27	516.00	-2.91	0.004
Perceived Intelligence	56.18	67	35.06	31	591.00	-3.61	0.000
Perceived Safety	57.45	67	32.32	31	506.00	-4.30	0.000
Perceived Trustworthiness	56.47	67	34.44	31	571.50	-3.75	0.000
Avoidance of Obstacles	53.50	67	40.85	31	770.50	-2.13	0.033
Obedience of Traffic Rules	53.80	67	40.21	31	750.00	-2.33	0.020

Results from the SCA indicated that participants in the main study had a favourable view of the AS service and technology. The SCA plots are presented in the Appendix. Of note, after examining the SCA plot for the Avoidance of Obstacles variable, four outliers from ratings of "slightly unacceptable" and "unacceptable" were detected and removed, leaving $n = 92$ for the analysis. The SCA plot for Perceived Trustworthiness had one outlier removed from ratings of "somewhat disagree," leaving $n = 95$ for the analysis. Similarly, the Perceived Safety plot revealed one outlier from ratings of "strongly disagree," leaving $n = 95$ for the analysis. Percent of variance explained by the dimensions is presented in Table 3.

For the Perceived Intelligence variable, the youngest group (19-27) was more highly associated with the highest level of agreement ("strongly agree"), while the older group (46-70) was more closely associated with a weaker positive response ("somewhat agree"). The middle age group 28-45 was associated with "agree" and "neither agree nor disagree." The closest association for the Regular Use of Shuttle variable was with individuals in the middle age group (28-45) who most frequently responded "agree." Other responses did not have close groupings. The Perceived Safety variable showed that individuals in the youngest age group (19-27) frequently strongly agreed that the shuttle was safe while participants in the middle age group (28-45) were neutral in opinion. The Perceived Trustworthiness variable did not have any patterns of note. The Avoidance of Obstacles variable showed an association between the 19-27 group with "strongly agree." Finally, for the Obedience of Traffic Rules variable, the closest frequency count was with individuals in the youngest group (19-27) finding the service "perfectly acceptable."

Table 3: Variance (%) Explained by Dimension 1 and 2 – Main Study.

Variable	Variance in Dimension 1	Variance in Dimension 2
Perceived Intelligence	57.86	42.12
Regular use of Shuttle	74.66	25.33
Perceived Safety	71.30	28,70
Perceived Trustworthiness	95.60	4.40
Avoidance of Obstacles	77.69	22.32
Obedience of Traffic Rules	72.04	27.96

4 DISCUSSION

The aim of this study was to explore rider and non-rider perceptions of an AS service and technology, along with their likelihood of recommending it to future users. Those who chose to ride in the AS were more likely to rate the shuttle positively and more likely to recommend the service to a friend or colleague. However, employees of the DoD were not as likely to recommend the AS when compared to non-DoD employees.

The open-ended feedback helped to identify some of the issues these participants felt about the AS. The first issue was related to the pre-defined route the AS had to follow, and many participants expressed a desire to see changes to the defined route with comments such as "More stops… maybe faster," "More hours," and "Better routes needed." There were also requests for specific changes to the route such as, "Stop closer to Hatfield Gate. In January, February, and March we have workshops at Brucker Hall and a shuttle between Hatfield Gate and Brucker would be very useful." This issue was also found in a similar AV study involving a shuttle on a set route (Eden et al., 2017). Second, participants made comments about the ride not being as smooth as they would like with sudden jerky acceleration and breaking, which Eden et al. (2017) also found was an issue for riders. One participant stated, “I sat in the back seat which made me nauseated with the jerky and fast stops and starts. I had to move to a side seat and sit with my legs toward the front to support me. I would not ride it again til that was fixed.” Third, some riders desired more clear communication regarding which stop the shuttle was at, along with information about unexpected situations such as stopping for a parked vehicle. This is backed up by the finding that an AV with an interface that communicates with passengers is found to be more trustworthy (Ruijten et al., 2018). Lastly, some participants were not fond of the size or arrangement of seating in the AS. Some passengers commented that they felt the seats were uncomfortable or should be larger. Additionally, all seats were placed along three sides of the shuttle and face inward, which forced participants to look towards each other or the door if they did not wish to interact with other riders. One participant remarked on the need for both, simply stating “larger, front facing seating.” Research conducted by Ong et al. (2019) in which typically shared transportation methods were partitioned off for privacy garnered similar feedback from participants who enjoyed the idea of avoiding interaction with a stranger during their ride.

The trends seen in the SCA plots suggest that the younger age group (e.g., ages 19-27 in the main study) usually reported higher levels of agreement and acceptance on the surveys. This was very prevalent when examining topics such as Perceived Safety and Avoidance of Obstacles. These findings were also seen in the results of the Chi-Square test in the pilot study that examined the association between vehicle safety and age, where the youngest group of participants were more likely to rate the AS as safe. However, in the main study, this trend was contrasted by the next age group (28-45), who reported neutral responses to Perceived Safety. It is surprising that this age group was the most associated with agreement that the AS service would see regular use despite generally not viewing it as particularly safe. More research should be conducted to further examine the perceptions from different age groups, in particular, the middle age group, to determine the motivations they may have about AS usage despite holding a lower view of its safety.

One of the limitations of this study was the use of a military base as the testing ground for the shuttle. While civilians were permitted onto the base to ride the AS, it is unlikely that this would be common knowledge for some people. Much of the sample consisted of DoD employees, where ideally the sample would have been more diverse. The sample may have also been impacted by the pilot phase of the study, in which one could only ride the AS by invitation. Without an invitation, potential users might have been turned away during this portion of data collection and might not have returned during the main study phase, although the research team encouraged some DoD employees to try out the service.

There was also a concern that participant answers were potentially influenced by the safety operators who were present during the AS rides. These operators were employees of the AS company and were trained to give a more interactive experience in which they gave a short presentation about the shuttle and participants could ask questions. It has been found that the presence of an employee onboard can influence overall willingness to ride for participants (Dong et al., 2019). The personable nature of the operators may have also softened criticism of the shuttle that some participants may have reported if they were to ride it without an operator present.

The survey itself also faced some limitations. Some participants had trouble receiving the email for completing the survey on-line. As it was not asked that they take it immediately, like the paper survey, and some participants did not complete it. The on-line survey also did not allow participants to revisit a question after it was answered. After the initial pilot phase, the wording for the question regarding comfort was altered. The initial survey used during the pilot study was also missing several questions that the later version in the main study covered.

Overall, this research suggests that those who experience an AS may hold a more positive outlook on the future of the technology. Addressing the negative feedback and desires of users will be beneficial in creating a positive AS experience and promoting the technology.

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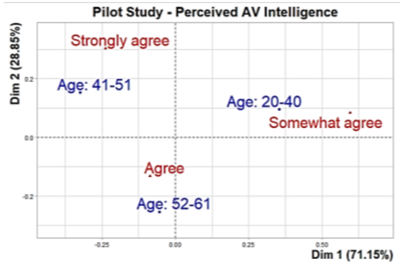
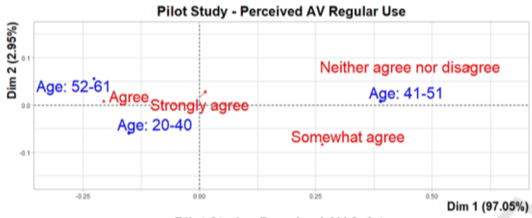
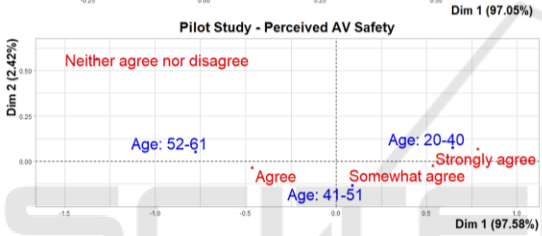
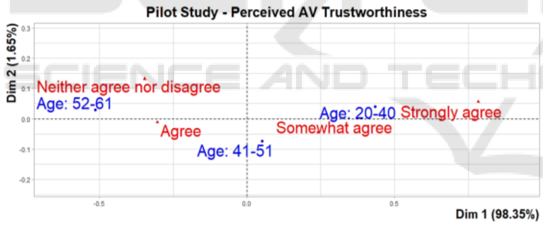
APPENDIX

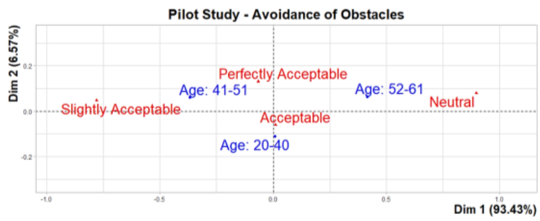
Pilot Study











Main Study