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Understanding Shared Autonomous Vehicle Preferences: A Comparison between Shuttles, Buses, Ridesharing and Taxis

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Abstract: Shared autonomous vehicles (AVs) will soon be introduced in public transportation as cities and their transportation systems become 'smarter'. This brings long-term environmental, economic and societal benefits to cities. However, shared AVs will not only need to overcome technological challenges but also prevail against social barriers for successful marketplace penetration. Hence, we proposed and investigated the acceptance of four shared AV service designs for public use in this study, namely, autonomous buses, shuttles, AV rideshares and autonomous or robo-taxis. An online survey conducted in Singapore with 734 adults found the greatest receptiveness toward the introduction of autonomous shuttles, in part due to perceptions that they will perform well and be easy to adopt. This aligns with ongoing shared AV trials where AV shuttles are mostly used. Larger autonomous buses had the second-highest acceptance. AV rideshares and taxis seem to largely appeal to the existing regular users of the conventional counterparts of these services. These results suggest that to encourage a mode switch from public transport to ridesharing and taxis, or vice versa, shared AVs need to appeal to users beyond being an automated version of existing modes. That is, shared AVs need to address an underserved or unmet transportation need or population.

Keywords: shared autonomous vehicles; technology acceptance; self-driving vehicles; mode preference; public transit

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1. Introduction

The new frontier of urban transportation is the introduction of shared autonomous vehicles (SAVs), which are driverless vehicles that can sense and navigate their environment without human operations. SAVs are essentially AVs that are shared by individuals in public settings, similar to public transit and vehicle-for-hire services available today. SAVs are currently being developed and tested in many cities, and most are intended for public transit services in the future. The introduction of SAVs has been envisioned to transform public transit systems and private vehicle ownership and use by bringing in new forms of shared mobility that are safer and more efficient [1]. This potentially increases the appeal and use of public transit, which will ease traffic congestion in cities. Coupled with improved fuel economy and reductions in emissions, SAVs can reduce the environmental impact of transportation as part of sustainable urban mobility plans [2]. SAVs would also make public transit more accessible, be it for underserved or elderly populations, since it affords services that are on-demand to low-demand or underserved areas reliably and safely [3,4]. The nature of AVs also reduces human errors and addresses manpower constraints, which is then freed up for jobs and services that require greater manpower [5]. Lastly, it is also envisioned that SAVs will contribute to keeping public transit affordable, as it reduces operating and manpower costs in the longer term despite the increased capital cost [6].

Despite the benefits that SAVs offer, such utilities can only be realized or maximized if there is widespread public acceptance and adoption of their services, where a critical mass in the use of SAVs services is achieved [7]. Cartenì [8] suggested that the reluctance for the mass public adoption of SAVs is a psychological, in addition to technological, reluctance, but the idea of introducing driverless vehicles is not new, especially in public transit, as many cities have deployed them in varying forms (e.g., driverless trains in subway and metro systems; [9]). However, deploying SAVs on the road will be different, as they share public roads and spaces with other vehicles and will have close interactions with the public, as opposed to being in confined, predetermined spaces. Hence, planning how AVs will be implemented often revolves around the idea of delivering optimal utility to users as well as to transportation service providers [10].

When designing public transportation using AVs, research has often used urban simulation models to search for the optimal design that maximizes the utility of various stakeholders. The design would include the use of different models of AVs (cars, shuttles, buses) that have varying passenger capacities [11]. These SAVs can be configured to provide on-demand or scheduled fixed-route mobility services. Fielbaum [12] suggested that a larger fleet of smaller vehicles (i.e., autonomous shuttles) configured as on-demand is more optimal in terms of flexibility and coordination, increasing the capacity of transportation passengers. However, Shen and colleagues [13] suggested that replacing short trips with SAVs will not improve utility, as short-trip SAVs would cover fewer miles per passenger. Additionally, the cost of operating a large fleet of SAVs may not be financially viable for transportation service providers. From the user perspective, Singleton [14] suggests that long-trip SAVs would increase productivity since the long-trip duration could provide users with more flexible time to do other things during the long journey. From these studies, it is clear that, presently, there is limited knowledge about the potential designs of SAV services and the public acceptance of the different designs. Thus, the question remains: What form should SAV services take on that would be acceptable to the public?

Answering this question necessitates that we explore specific SAV service designs. Past studies that have studied SAVs did so more generally, without going into detail about the design of the SAV service. Past research studied SAVs ranging, in terms of passenger capacity, from as little as 1 to 4 passengers for shared AV cars to 40 passengers for large AV buses (e.g., [3,12,15–18]), but they focused on perceptions and the acceptance of the vehicle rather than the service design. This means that there is great heterogeneity between the types of SAVs that have been studied and a potential discrepancy between what has been studied and what is actually practicable and implementable as SAV services. Hence, there is a need to develop a better understanding of public opinion and the acceptance of the different designs of SAV services [19]. Doing so will play an important role in their rapid adoption and implementation [20]. It is important to understand the perception of users to understand their acceptance and incorporation into existing modes of transportation [21–23]. Further, this will also support policy decisions for upgrading existing infrastructure, changes in transportation and urban planning and regulations to support the implementation of SAVs in cities [24,25].

To address the above knowledge gaps, we explored the acceptance of four different types of SAV service designs for dense cities, designed by the research team in collaboration with an automobile manufacturer. Specifically, we investigated the following research questions:

(1) Establishing the level of acceptance for the four SAV service designs:
   a. What is the level of acceptance of each service design?
   b. How does the level of acceptance differ across service designs?
   c. Which SAV service design is most readily accepted?
(2) Identifying the predictors of acceptance for each SAV service design:
   a. How do the expectation of performance, the ease of use and the level of familiarity with AVs predict acceptance?
   b. How does acceptance differ across different sociodemographic groups?

2. Shared Autonomous Vehicle Service Designs

Hao and Yamamoto [26] reviewed carsharing and autonomous vehicles and proposed that SAVs overlap with existing modes of public transportation, taxis and carsharing. This was useful for helping us understand and conceptualize where SAVs will fit within the transportation system and the modes that it might potentially replace or augment. However, for the purpose of this study, we needed more specific designs of SAVs that are potentially suitable for dense cities. Hence, the research team collaborated with an automobile manufacturer to design four types of SAV services that are most likely to be deployed in dense cities, either as complements or replacements for existing public transit systems and shared services (e.g., taxis and private-hire vehicles). The four SAV services proposed were all rated as feasible for introduction to public use by our industry collaborator and would serve to enhance existing transportation accessibility. These four SAV service types differ by the extent of their potential exclusivity (public sharing vs. limited or no public sharing) and the type of service they provide (scheduled vs. on-demand; fixed vs. dynamic route). We list the four types of SAVs with their specifications in Table 1.

Table 1. Four shared autonomous vehicle service designs.

Type of AVs	Vehicle Capacity	Exclusivity	Type of Service	Potential Services
Autonomous bus	Up to 40	Non-exclusive; public service	Scheduled and on-demand; fixed pickup/dropoffs	Trunk/long-distance services
Autonomous shuttle	Up to 11	Non-exclusive; public service	Scheduled and on-demand; fixed pickup/dropoffs	Feeder/short-distance services
Autonomous rideshare	Up to 4	Semi-exclusive; limited public sharing	On-demand; flexible pickup/dropoffs	Ridesharing
Autonomous taxi	Up to 4	Semi-exclusive; no public sharing	On-demand; flexible pickup/dropoffs	Private-hire/taxi

3. Methodology

3.1. Study Context

KPMG's 2020 Autonomous Vehicle Readiness Index ranks Singapore as being the readiest to adopt AVs, leading in consumer acceptance and, policy and legislation rankings [27]. The Southeast Asian city-state has been developing and prototyping different forms and applications of AVs and was the first to test commercial autonomous mobility-on-demand services in 2016 [28]. Since 2018, AV shuttles have been tested on public roads [29], and in 2019, it was one of the first cities to test 40-seater AV buses [30]. Singapore's Land Transport Authority (LTA) announced plans to deploy SAVs in three new towns (Punggol, Tengah and the Jurong Innovation District) in the mid-to-late 2020s [31] and recently expanded AV testing to all public roads in the city's western half [32].

Public transportation is widely used by Singapore's population of 5.69 million and is the backbone of its transportation system [33]. In total, 4 million bus and 3.5 million subway and light rail daily transit rides were recorded in 2018 [34]. Public transportation's peak hour mode share was 67% in 2016 and is set to increase to 75% by 2030 [35]. To curb the private vehicle population and further encourage public transportation ridership in a land-scarce city, the private vehicle growth rate was revised downward to 0% in February 2018 [36]. A further introduction and discussion about Singapore's transportation system and the travel behavior of its residents can be found in [37].

SAVs are being explored to improve the public transportation network and to address constraints faced in terms of land and manpower [38]. In 2014, a government committee on Autonomous Road Transport was founded to chart the strategic development of AV-enabled land mobility concepts [39]. In addition, the Singapore AV Initiative was formed to investigate the technological and economic opportunities of AVs [40]. These form part of Singapore's strategy for addressing its growing demand for transportation in a population that is aging and constrained by land scarcity and manpower challenges. Hence, transitioning to SAVs in public transportation is a significant and critical development for Singapore to meet its transportation demands.

3.2. Participants

The data were collected via an online survey in Singapore conducted from September to November 2019 with the assistance of an independent research marketing company. To focus on resident transportation users, the survey was only distributed to people who resided in Singapore. In total, responses from 734 adult participants were collected, of which 394 (53.4%) were female. The sample was a representation of the diversity of the adult resident population in Singapore across age, gender and monthly household income (see Table 2 for further details). The participants had a diverse range of education: the largest group (48.5%) had received a Bachelor's degree, and a further 8.7% reported having a post-graduate degree. The majority were also employed (87.7%) and staying in HDB flats (public housing) (79%). Within the sample, 89.6% regularly commuted to work or school. Though our sample is younger and more highly educated than the general population of Singapore, they are also the current and future generation of SAV users for when SAVs are tested and subsequently implemented by the end of this decade in Singapore.

Table 2. Sample demographics and mobility profile (N = 734).

Demographics				**Mobility**		
	n	% within group	% of population		*n*	% within group
Age				Concession pass		
21–29	107	14.6	17.0	Yes	154	21.0
30–39	194	26.4	18.0	No	580	79.0
40–49	225	30.7	20.0	Car driver's license		
50+	208	28.3	45.0	Yes	546	74.4
Gender				No	188	25.6
Female	394	53.7	51.1	Public transport use		
Male	340	46.3	48.9	Regular	563	76.7
Monthly household income				Occasional	171	23.3
<SGD 2000	56	7.6	17.4	Ridesharing use		
SGD 2000–SGD 3999	111	15.1	11.3	Regular	120	16.3
SGD 4000–SGD 5999	125	17.0	11.6	Occasional	614	84.7
SGD 6000–SGD 9999	198	27.0	21.2	Disability affecting mobility		
SGD 10,000 and above	244	33.2	38.6	Yes	48	6.5
Education				No	686	93.5
O levels and below	107	14.6	42.7	Car ownership within household		
A levels/diploma	198	27.0	24.9 [a]	None	233	31.7
Bachelors	356	48.5	32.3 [b]	1	427	58.2
Masters and above	64	8.7		2 or more	74	10.1
Others	9	1.2		Commute satisfaction (Commuters only; *n* = 658)		

Table 2. *Cont.*

Demographics				**Mobility**		
Dwelling type				(Very) Dissatisfied	38	5.8
HDB	580	79.0	78.3	Neither satisfied nor dissatisfied	130	19.8
Condominium/private flat	124	16.9	14.6	Satisfied	361	54.9
Landed property/others	30	4.1	7.0	Very satisfied	129	19.6
Employment status						
Employed	644	87.7				
Student/Retired/Unemployed	90	12.3				

Percentages are rounded figures and may not add up to 100%. The data for the percentages of the Singapore population were from the Department of Statistics of Singapore. [a] This figure includes 'Others'. [b] This figure includes 'Masters and above'.

3.3. Survey Design

The survey started with questions collecting information about the participant's age, gender, monthly household income, education, dwelling type and employment status. Next, questions were asked about the participant's driver's license, public transportation concession pass usage, public transportation and ridesharing use and car ownership within the household. Further questions addressed the presence of disabilities that might affect mobility. Finally, participants who commute (for work or school) were asked about their level of satisfaction with their current commute using a five-point Likert scale (from very dissatisfied to very satisfied). As only 2 participants responded that they were 'very dissatisfied' with their commute, this response category was combined with the 'dissatisfied' category to form a final four-point Likert scale for analysis.

Next, we established the participant's level of familiarity with AVs prior to this study. All participants were asked the question, "Have you ever heard of autonomous or driverless vehicles", to which they could answer either yes or no. Participants who answered yes to the question were asked the follow-up question, "How familiar are you with the concept of autonomous or driverless on-road vehicles", to which they could respond on a five-point Likert scale ranging from extremely familiar to not familiar at all. Following these questions, participants were presented with a brief introductory text explaining what autonomous vehicles are and that there were AV trials taking place in Singapore at the time of the study (see Appendix A) to ensure they proceeded to the rest of the study with the same level of understanding of AVs in Singapore.

Participants were then asked a series of questions regarding each SAV service design. Prior to that, they were presented with an introduction together with picture illustrations (see Appendix B). Two sets of three questions were asked about the perceived usefulness and perceived ease of use of the design on a five-point Likert scale (strongly agree to strongly disagree) with an additional option of 'unsure' if participants felt that they were unable to answer the questions. Both scales were adapted from the unified theory of acceptance and use of technology [41] and across all four SAV service designs demonstrated good internal reliability with Cronbach's alpha, ranging from 0.79 to 0.89 (see Table 3).

The acceptance of the SAV service designs was operationalized in two manners: the intention to sign up for a trial and the intention to use the SAV service when implemented. This distinction is important, as SAVs will first be trialled and then implemented, and the time between these two phases is significant. SAV implementers and policymakers would benefit from understanding the subtle differences between users and acceptance in these two phases. Accordingly, participants were asked about their intention to sign up for a trial involving the SAV service design in question (i.e., I will sign up for a trial involving (SAV service design)), followed by their intention to use the same SAV service when it is implemented (i.e., I will use (SAV service design) when it is introduced). Again, the responses were made on a five-point Likert scale (strongly agree to strongly disagree) with the additional option of 'unsure' if participants felt that they were unable to answer the questions. The customized versions of these questions were repeated for each of the four SAV service designs (see Appendix A for the questionnaire administered). The study was approved by the Institutional Review Board of the Singapore University of Technology and Design.

Table 3. Means and standard deviations of the perceived usefulness and ease of use, as well as the intention to participate in a trial and to use each shared AV design.

	AV Bus			AV Shuttle			AV Rideshare			AV Taxi			*p*
	Mean	**SD**	**Unsure %**	**Mean**	**SD**	**Unsure %**	**Mean**	**SD**	**Unsure %**	**Mean**	**SD**	**Unsure %**	
Perceived usefulness (PU)	3.16	0.88		3.41	0.87		3.32	0.86		3.35	0.89		0.001
PU1	3.18	1.01	6.54%	3.40	0.96	6.27%	3.32	0.96	7.49%	3.37	1.00	5.86%	
PU2	3.15	0.99	6.68%	3.43	0.96	6.40%	3.34	0.96	6.54%	3.37	0.96	6.81%	
PU3	3.19	1.01	6.27%	3.46	0.95	7.49%	3.36	0.95	6.54%	3.35	0.98	7.08%	
Cronbach's alpha	0.85			0.89			0.87			0.89			
Perceived ease of use (PE)	3.37	0.80		3.60	0.83		3.41	0.83		3.44	0.83		0.001
PE1	3.47	0.93	7.49%	3.63	0.88	6.81%	3.48	0.93	5.72%	3.52	0.91	8.17%	
PE2	3.47	0.92	7.49%	3.59	0.89	7.63%	3.47	0.93	7.90%	3.52	0.92	7.22%	
PE3	3.23	0.95	7.22%	3.45	0.94	7.63%	3.32	0.92	7.49%	3.35	0.96	7.22%	
Cronbach's alpha	0.79			0.85			0.86			0.86			
Intention to participate in trial	3.46	1.06	5.72%	3.57	1.02	5.45%	3.40	1.08	5.86%	3.47	1.10	5.04%	0.03
Intention to use when implemented	3.54	1.00	3.81%	3.64	0.98	4.77%	3.43	1.05	5.04%	3.45	1.05	5.04%	0.001

p-values indicate results from univariate ANOVA tests conducted for each variable across shared AV designs.

4. Results and Discussion

4.1. Familiarity with AVs

The majority of our participants (n = 693; 86.2%) had heard about AVs prior to this study, of which 85% (n = 538) said that they had at least some familiarity with AV technology. A smaller proportion of participants (n = 120; 16.3%) were very familiar or extremely familiar with AVs. We observed that male, younger and higher-educated participants reported significantly higher levels of familiarity in general; all Chi-square tests < 0.01 (see Figure 1).

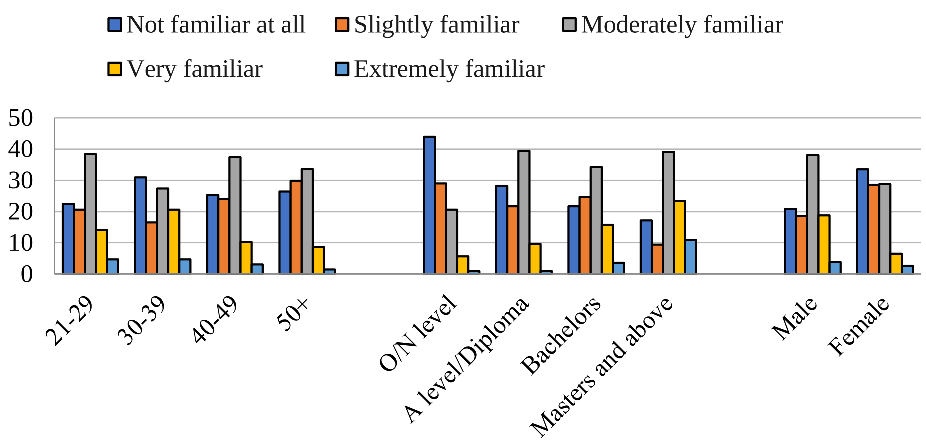

Figure 1. Self-reported familiarity with AVs across age, education and gender. Note: Results for 'other' education qualifications are not presented because of the small number of responses (n = 9).

4.2. Perception and Acceptance of Shared AV Services

Participants reported perceptions that all four SAV services were useful (mean scores ranging from 3.16 to 3.41, out of 5) and easy to use (mean scores ranging from 3.37 to 3.60). In both measures of the acceptance of SAV services, we found that participants were willing to participate in all four SAV services trials (mean scores ranging from 3.40 to 3.57) and to use them when they are implemented (mean scores ranging from 3.43 to 3.64). Detailed results for each SAV service are presented in Table 3.

Next, we investigated potential differences between the perception of usefulness and ease of use, as well as the intention to participate in a trial and use the service for each SAV service across age, gender and education differences using multivariate analysis of variance. We found significant overall differences for SAV bus services (F (32, 2380) = 1.92, $p < 0.01$; Wilk's $\Lambda = 0.91$, partial $\eta^2 = 0.03$), with further analyses revealing that male, compared with female, participants reported a significantly stronger perception that AV buses were easy to use (F (1, 708) = 14.15, $p < 0.0125$) and greater intentions to participate in AV bus trials (F (1, 691) = 6.90, $p < 0.0125$) and use AV buses when implemented (F (1, 705) = 10.29, $p < 0.0125$). In addition, participants with at least a bachelor's education reported significantly greater intentions to participate in AV bus trials than the rest of the participants (F (4, 691) = 4.30, $p < 0.0125$). However, no significant differences were observed across ages. For SAV shuttle services, no significant differences were found in the combined variables (F (32, 2358) = 1.31, $p > 0.05$; Wilk's $\Lambda = 0.94$, partial $\eta^2 = 0.02$). However, individual MANOVA tests for gender revealed significant differences (F (4, 639) = 2.54, $p < 0.05$; Wilk's $\Lambda = 0.98$, partial $\eta^2 = 0.02$), with male, compared with female, participants reporting a significantly stronger perception that AV shuttles were easy to use (F (1, 698) = 7.18, $p < 0.0125$) and greater intention to participate in AV shuttle trials (F (1, 693) = 9.52, $p < 0.0125$). For AV rideshare and taxi services, no significant age, gender or education differences were found for SAV rideshare (F (32, 2358) = 1.22, $p > 0.05$; Wilk's $\Lambda = 0.94$, partial $\eta^2 = 0.02$) and taxi services (F (32, 2410) = 1.12, $p > 0.05$; Wilk's $\Lambda = 0.95$, partial $\eta^2 = 0.02$).

4.3. Differences across Shared AV Services

The differences between the perceptions and acceptance across SAV services were examined. MANOVA results revealed significant differences in the combined variable across the SAV services (F (12, 7750) = 7.93, $p < 0.001$; Wilk's $\Lambda = 0.97$, partial $\eta^2 = 0.01$). Further analyses found that participants perceived SAV shuttles as significantly more useful (mean (sd) = 3.57 (0.80)) and easy to use (mean (sd) = 3.40 (0.84)), while perceiving SAV buses as the least useful (mean (sd) = 3.16 (0.85)) and easy to use (mean (sd) = 3.36 (0.76)). Participants expressed significantly higher intentions to participate in SAV shuttle trials (mean (sd) = 3.54 (1.00)) and use them when implemented (mean (sd) = 3.60 (0.96)) compared with the remaining three services.

4.4. Predictors of Intention to Participate in Shared AV Trials

Multivariate linear regressions were conducted to identify predictors of intentions to participate in SAV trials, and the results are summarized in Tables 4–7. First, perceptions of usefulness and ease of use and level of AV familiarity were modeled. Both perceptions of usefulness (all Bs ranged from 0.28 to 0.40 and ps < 0.001) and ease of use (all Bs ranged from 0.42 to 0.58 and ps < 0.001) predict greater intentions to participate in all four SAV trials. Familiarity with AVs was a significant predictor for all trials except SAV bus trials. Next, demographic variables were added to the models and the perceptions of usefulness (all Bs ranged from 0.28 to 0.39 and ps < 0.001) and ease of use (all Bs ranged from 0.41 to 0.58 and ps < 0.001) continued to be associated with greater intentions to participate in the respective trials. However, familiarity with AVs was no longer associated with intentions to do so, indicating that familiarity with AVs can be explained by demographic differences. Additional demographic predictors were also identified for all SAV services, except for SAV shuttles. Regular public transport users reported greater intentions to participate in AV bus trials than occasional users (B = 0.19, $p < 0.01$). Participants with driver's licenses also reported greater intentions to participate in AV rideshare trials (B = 0.24, $p < 0.001$). Lastly, regular ridesharing users reported greater intentions to participate in AV taxi trials (B = 0.23, $p < 0.01$). Detailed results are in Supplementary Table S1.

4.5. Predictors of Intention to Use Shared AV Services When Implemented

Similar multivariate linear regressions modeled the intention to use each SAV service when implemented, and the results are summarized in Tables 4–7. Again, perceptions of usefulness and ease of use and the level of AV familiarity were modeled first. The perceptions of usefulness (all Bs ranged from 0.24 to 0.43 and *p*s < 0.001) and ease of use (all Bs ranged from 0.51 to 0.67 and *p*s < 0.001) were associated with greater intentions to use all four SAV services when implemented. Familiarity with AVs only predicted intentions to use SAV rideshares for those who reported being 'very familiar' (B = 0.20, $p < 0.05$), expressing greater intentions than those who were unfamiliar. Next, demographic variables were added to the models, and the perceptions of usefulness (all Bs ranged from 0.24 to 0.44 and *p*s < 0.001) and ease of use (all Bs ranged from 0.47 to 0.67 and *p*s < 0.001) continued to be associated with greater intentions to use all four SAV services. Familiarity with AVs no longer predicted intentions to do so. Additional demographic predictors were identified for SAV bus and shuttle services. Participants in the monthly household income band of SGD 4000 to SGD 5999, compared to those in the <SGD 2000 band, reported greater intentions to use SAV buses (B = 0.29, $p < 0.05$). Participants who were unemployed, students or retired, compared with those employed, reported lower intentions to use SAV shuttles (B = −0.17, $p < 0.05$). Detailed results are in Supplementary Table S2.

Table 4. Predictors of shared AV bus acceptance in trials and when implemented.

	Intention to Participate in Trials (Coefficients)			**Intention to Participate in Trials (Coefficients)**		
	AV Predictors Only	**With Demo-graphics**	**Commuters Only**	**AV Predictors Only**	**With Demo-graphics**	**Commuters Only**
Perceived performance	0.28 **	0.28 **	0.27 **	0.24 **	0.24 **	0.21 **
Perceived ease of use	0.57 **	0.57 **	0.58 **	0.58 **	0.58 **	0.60 **
AV familiarity						
Not familiar at all	ref	ref	ref	ref	ref	ref
Slightly familiar	−0.01	−0.04	−0.06	0.08	0.08	0.07
Moderately familiar	0.12	0.08	0.04	0.04	0.03	0.06
Very familiar	0.16	0.07	0.07	0.15	0.13	0.20
Extremely familiar	0.11	0.05	0.07	0.15	0.20	0.35

** $p < 0.001$.

Table 5. Predictors of shared AV shuttle acceptance in trials and when implemented.

	Intention to Participate in Trials (Coefficients)			**Intention to Participate in Trials (Coefficients)**		
	AV Predictors Only	**With Demo-graphics**	**Commuters Only**	**AV Predictors Only**	**With Demo-graphics**	**Commuters Only**
Perceived performance	0.40 **	0.39 **	0.37 **	0.42 **	0.43 **	0.39 **
Perceived ease of use	0.42 **	0.41 **	0.41 **	0.51 **	0.51 **	0.52 **
AV familiarity						
Not familiar at all	ref	ref	ref	ref	ref	ref
Slightly familiar	−0.09	−0.11	−0.09	−0.04	−0.05	−0.06
Moderately familiar	0.09	0.07	0.10	0.08	0.08	0.11
Very familiar	0.22 *	0.16	0.21 *	0.13	0.12	0.18 *
Extremely familiar	0.33 *	0.28	0.42 *	0.11	0.08	0.16

* $p < 0.05$; ** $p < 0.001$.

Table 6. Predictors of shared AV rideshare acceptance in trials and when implemented.

	Intention to Participate in Trials (Coefficients)			Intention to Participate in Trials (Coefficients)		
	AV Predictors Only	With Demographics	Commuters Only	AV Predictors Only	With Demographics	Commuters Only
Perceived performance	0.35 **	0.33 **	0.31 **	0.43 **	0.44 **	0.41 **
Perceived ease of use	0.58 **	0.58 **	0.60 **	0.52 **	0.51 **	0.53 **
AV familiarity						
Not familiar at all	ref	ref	ref	ref	ref	ref
Slightly familiar	0.02	0.05	0.10	0.06	0.04	0.02
Moderately familiar	0.15 *	0.12	0.17	0.10	0.05	0.08
Very familiar	0.09	0.01	0.07	0.20 *	0.14	0.15
Extremely familiar	0.13	0.08	0.22	0.13	0.10	0.18

* $p < 0.05$; ** $p < 0.001$.

Table 7. Predictors of shared AV taxi acceptance in trials and when implemented.

	Intention to Participate in Trials (Coefficients)			Intention to Participate in Trials (Coefficients)		
	AV Predictors Only	With Demographics	Commuters Only	AV Predictors Only	With Demographics	Commuters Only
Perceived performance	0.38 **	0.38 **	0.33 **	0.29 **	0.29 **	0.23 **
Perceived ease of use	0.57 **	0.56 **	0.60 **	0.67 **	0.67 **	0.71 **
AV familiarity						
Not familiar at all	ref	ref	ref	ref	ref	ref
Slightly familiar	−0.01	0.01	0.06	0.00	0.01	0.00
Moderately familiar	0.09	0.07	0.12	0.00	−0.02	0.01
Very familiar	0.19 *	0.12	0.18	−0.02	−0.08	−0.06
Extremely familiar	0.21	0.19	0.28	−0.03	−0.10	−0.02

* $p < 0.05$; ** $p < 0.001$.

4.6. Predictors of Shared AV Service Acceptance among Regular Commuters

Additional sub-sample analyses were conducted with commuters to identify potential differences in their acceptance of SAV services. The perceptions of usefulness (all Bs ranged from 0.21 to 0.41 and ps < 0.001) and ease of use (all Bs ranged from 0.41 to 0.71 and ps < 0.001) continued to predict intentions to participate in trials or to use all four SAV services. Familiarity with AVs only predicted intentions to use and participate in SAV shuttle trials, with those 'very familiar' (B = 0.21, $p < 0.05$) and extremely familiar' (B = 0.43, $p < 0.05$) with AVs reporting greater intention to participate in trials, and those 'very familiar' (B = 0.18, $p < 0.05$) reporting greater use intentions. Different demographic predictors were identified. Compared with working commuters, students reported lower intentions to participate in SAV rideshare (B = −0.62, $p < 0.05$) and taxi trials (B = −0.72, $p < 0.01$). Commuters with driver's licenses reported greater intentions to participate in AV rideshare trials (B = 0.22, $p < 0.01$). Regular ridesharing commuters also reported greater intentions to participate in SAV taxi trials (B = 0.23, $p < 0.01$).

Here, we also modeled an additional variable measuring commute satisfaction and found that it predicted intentions to participate in trials and use SAV buses. Compared with commuters who were dissatisfied with their commutes, those who were neither satisfied or dissatisfied reported greater intentions to participate in SAV bus trials (B = 0.31, $p < 0.05$). However, those who were very satisfied reported lower intentions to use SAV bus services when implemented (B = −0.21, $p < 0.05$). Detailed results are in Supplementary Tables S1 and S2.

5. Conclusions

5.1. Summary

The objective of this study was to examine the public acceptance of four plausible SAV service designs to be offered in cities and identify the predictors of acceptance. The four designs investigated were autonomous buses, shuttles, rideshares and taxis, which varied by the extent of their potential exclusivity (public sharing vs. limited or no public sharing) and the type of service they provide (scheduled vs. on-demand; fixed vs. dynamic route). All four designs potentially cater to different passengers and travel needs. We found strong acceptance for all four SAV services, both in terms of intention to participate in a trial and to use the service when implemented. This is consistent with previous studies on AV acceptance in Singapore (e.g., [42–44]).

These findings suggest the greatest receptiveness toward the introduction of SAV shuttles for public use, in part due to stronger perceptions that they will perform well and be easy to adopt. This mirrors ongoing AV trials in public transportation, where AV shuttles and smaller-capacity AVs are mostly used. However, AV buses, with larger capacity, have the second-highest acceptance despite perceptions that they will not perform as well and not be as easy to use as the other SAV services studied. This could partly be due to the early stage of development of AV buses, which means that they are less known and visible to the public. AV rideshares and AV taxis, on the other hand, seem to largely appeal to existing regular users of the conventional counterparts of these services (ridesharing and taxis). These suggest that if a SAV service intends to encourage a mode switch from public transport to ridesharing and taxis, or vice versa, it needs to appeal to users beyond being a driverless version of their existing travel modes; that is, it needs to address an underserved or unmet transport need or population.

The level of familiarity with AVs was found to be less important than perceptions that the SAV service is easy to use and will perform well when predicting public acceptance. Furthermore, the observed effects of familiarity with AVs were also explained by the sociodemographic characteristics of the participants. This highlights the practical considerations of participants when considering SAV services, consistent with previous findings reported by [16].

5.2. Implications for Strategy and Policy

This study provides several recommendations for transport planners, transport operators and AV manufacturers when developing SAV services for cities. The four SAV service designs were positively accepted by participants, and they might be considered by transport planners and operators when implementing AVs in the transportation network and by AV manufacturers when designing AVs that are meant for shared services. In addition, the primary focus when designing SAV services should be to design them to be useful and easy to use in order to enhance acceptance when implemented. This might be achieved by focusing on the improvements that these new SAV services will bring to the user's travel experience. Furthermore, government agencies can contribute to the development and successful implementation of SAV services. They can enable infrastructure and the requisite urban planning, such as 5G networks and identifying suitable pick-up and drop-off locations, and expand trial zones and awareness programs that influence the performance and ease of using SAV services.

5.3. Limitations and Research Recommendations

This study has a few limitations. The SAV service designs proposed in this study and findings on their acceptance are highly grounded in the Singapore context, where AV development has had much publicity and public transit is the main transportation mode. in This and previous studies, the population has also exhibited a higher propensity for the acceptance and adoption of new innovations, including AVs. Therefore, the interpretation and application of our findings, in practice, should be implemented in consideration of the contexts they were derived from; all countries and cities are unique. Further, these results are from the general population, and there may be other transportation user groups who might have specific needs and considerations that may not be adequately captured in this study [25].

Theoretically, SAV services have an advantage in urban regions, such as Singapore in this case, due to high population density, which pools demand and facilitates sharing AVs and, hence, SAV services. It might be equally advantageous to implement them in areas currently underserved by public transportation (e.g., rural areas where aggregated transport demand is lower), but this was not within the scope of this study and is less applicable in Singapore. Nonetheless, future work could use the four SAV service designs proposed, consider examining their applicability and cross-validate them with other urban and rural contexts. The study also investigated perceptions rather than reality. This was because SAV services are not currently available, and, further, the underlying assumption is that an individual's perception of SAV services is more important than reality in influencing their acceptance of these services, as perception is very often more important than reality. Nevertheless, in the near future, when early trial versions of SAV services are available, similar studies of acceptance should be replicated to validate the findings presented here.

A limited set of predictors of acceptance was explored in this study even as more comprehensive and dedicated theories of AV acceptance have emerged (e.g., the multi-level model on automated vehicle acceptance by [22]). Hence, future studies could look into employing these more comprehensive theories in their investigations to better account for the multi-faceted nature of decision-making surrounding AV acceptance [45]. This study also acknowledges that the obtained data are hypothetical, due to the use of a stated preference survey, and cross-sectional in nature. Future studies could consider the use of experimental research designs to understand the key factors contributing to the acceptance of SAVs (e.g., [46], which used a Turing approach to study if humans were able to recognize automated driving). Lastly, similar research on the perceptions and acceptance of different SAV designs should be conducted over an extended period, i.e., longitudinally, to track and analyze the diffusion of AV acceptance in society, especially when SAV services are piloted and implemented in cities with different characteristics.

These limitations notwithstanding, in this study, we presented four potential shared AV designs for cities that cater to different passengers and travel needs, varying by the extent of their potential exclusivity (public sharing vs. limited or no public sharing) and the type of service they provide (scheduled vs. on-demand; fixed vs. dynamic route). Strong acceptance was found for all four SAV services, both in terms of intention to participate in a trial and to use the service when implemented, which is encouraging as the industry, transportation operators and policymakers work toward introducing shared AV services in our cities in the coming years.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142013656/s1, Table S1: Intention to participate in shared AV trials; Table S2: Intention to use shared AV services when implemented.

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Appendix A. Introduction to AVs in Singapore

"Automated vehicles are now being tested on public roads by companies. These vehicles still have a steering wheel and pedals, and require a qualified driver to monitor and to take back control when needed. This questionnaire is about the next level of automation for driverless vehicles. Driverless vehicles operate without a driver and do not have a steering wheel, gas or brake pedals. In the beginning, they will not operate on all roads and not in all traffic situations. The driverless vehicles can come in different sizes and forms, from 40-seater driverless buses to smaller 14-seater driverless shuttles to private cars.

There are a number of trials taking place now in Singapore where driverless vehicles are tested on the roads. With this survey, we would like to find out what do you think about these driverless vehicles and whether you would be ready and willing to accept and use them."

Appendix B. Introduction to the Studied Shared AV Service Design

"Autonomous Buses: Imagine that a driverless bus is picking you up at a public transport stop (e.g., bus, MRT, LRT) to drive you to another public transport stop close to your destination. As the vehicle can accommodate up to 40 passengers, it is very likely that you share the vehicle with a group of unknown travelers traveling in the same direction as you.

Autonomous Shuttles: Imagine that a driverless shuttle is picking you up outside the train station or some other public transport stop (e.g., bus, MRT, LRT) to drive you to your final destination, providing last-mile transport. It can also drive you back to your original destination. You can book a driverless shuttle in advance and a driverless shuttle that best matches your destination will pick you up. As the vehicle can accommodate 6–8 passengers, it is very likely that you share the vehicle with a few unknown travellers going to the same destination.

Autonomous Rideshares: Imagine that a driverless rideshare is picking you up outside your house or at a location of your choice to drive you to your final destination, providing door-to-door transport. You can book a driverless rideshare in advance and a driverless rideshare vehicle that best matches your destination will pick you up. Since the vehicle can accommodate 3–4 passengers, you may share the ride with others heading in the same direction.

Autonomous Taxis: Imagine that a driverless taxi is picking you up outside your house or at a location of your choice to drive you to your final destination, providing door-to-door transport. You can book a driverless taxi in advance. You will travel alone in the vehicle or only with people you invite.

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