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Transportation Research Procedia 52 (2021) 533–540

Transportation Research Procedia

www.elsevier.com/locate/procedia

23rd EURO Working Group on Transportation Meeting, EWGT 2020, 16-18 September 2020, Paphos, Cyprus

A study of users' preferences after a brief exposure in a Shared Autonomous Vehicle (SAV)

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Abstract

Shared Autonomous Vehicles are expected to significantly change transport and mobility, improving road safety, environmental impact and traffic efficiency. However, the successful implementation of a SAV mobility service strongly depends on public acceptance and adoption, which might be influenced by a number of factors, such as socio-demographic characteristics of potential users, and their expectations and perceptions towards the autonomous system. This study presents the results of a novel experiment carried out in a non-simulated environment, to explore car users' preferences towards autonomous mobility options. Participants took part in a stated preference task before and after a brief exposure in a Shared Autonomous Vehicle. Interestingly, results show that the experience influenced people's mode choice preferences, moving from car (the most preferred mode before the experiment) to autonomous taxi and shared autonomous taxi (after the experiment). The study and the results of the structural equation and the choice model also highlighted the importance of comfort in people's preferences towards shared autonomous options.

Keywords: Shared Autonomous Vehicles (SAVs); Choice Modelling; Comfort; Acceptance;

1. Introduction

Shared Autonomous Vehicles (SAVs) represent an emerging alternative for driverless and on-demand transport (Fagnant and Kockelman, 2018), offering a compromise between private ownership and public transport (Haboucha et al., 2017). Ridesharing, fleet optimisation and downsizing, less congestion, and lower energy consumption are potential benefits of SAV over individual ownership of AV (Lu et al., 2018; Shaheen and Cohen, 2013; Fagnant and

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10.1016/j.trpro.2021.01.063

Kockelman, 2015; Meyer and Shaheen, 2017; Cai et al., 2019). SAVs also have potential through providing last/first-mile solutions for areas of low accessibility, and for integration with other modes such as public transport (Kröger et al., 2016). They may in fact be seen to be a particularly option due to their high flexibility (e.g. door-to-door service) and therefore become a competitor to traditional public transport. They may also be seen as more convenient than private transport by allowing activities to be undertaken during the journey. Moreover, they would likely be cheaper than an exclusively-used automated taxi. However, it is worth noting that the SAV user experience is likely to involve lower privacy, lower space availability, and a less seamless travel experience than a private car as the vehicle might divert from the shortest-path route to service other passengers.

Overall, travel cost, travel time and waiting time are key attributes for the acceptance of SAV (Kröger et al. 2016), especially within a Dynamic Ride Sharing (DRS) environment (i.e. people share with strangers). However, a successful implementation of SAVs would also depend on people's willingness to use the autonomous technology and to share the vehicle with unfamiliar others (Seuwou et al., 2017; Zhang et al. 2019; Cunningham and Regan, 2020). For this reason, researchers have investigated the main factors that can influence public acceptance of AVs and SAVs and sought to theorise acceptance models. Probably of greatest influence has been the Technology Acceptance Model (TAM), developed by Davis (1989), which is based on the Theory of Planned Behaviour - TPB (Ajzen, 1991). At its core is the concept that users accept and adopt the technology if they perceive it is useful (Perceived Usefulness -PU), easy to use (Perceived Ease of Use – PeoU) and if they have the behavioural intention (BI) to use it. Other researchers have then further developed the theories towards public acceptance and identified factors that can influence willingness to use AVs, such as safety (Xu et al. 2018), usefulness, self-efficacy, risk, and psychological ownership (Lee et al. 2019). Perceived benefits of AVs, such as congestion reduction and polluting emissions reduction were found to have a significant positive effect on acceptance (Acheampong and Cugurullo, 2019). A number of other studies found time sensitivity (Lavieri and Bath, 2019) and trust in new technologies (Choi and Ji, 2015) are also important factors influencing willingness to use AVs.

Siebert et al. (2013) and Bellem et al. (2019) found statistically significant relationships between trust and comfort in AVs, and Paddeu et al. (2020) found that, together with trust, comfort is also an important predictor of acceptance and adoption of SAVs. However, comfort in SAVs has barely been explored. Similar to trust, comfort is subjective (de Looze et al., 2003), is influenced by external factors that have a direct effect on the body, and is experienced as a reaction to something. The literature provides a great number of studies that investigate car drivers' comfort, mainly related to physical parameters (e.g. temperature, noise, vibrations, lighting, driving position) with a direct effect on perceived comfort (Zuska and Więckowski, 2018). Another important factor is related to the operational conditions of driving, such as acceleration and vibration (Eriksson and Friberg, 2000; Hu et al., 2017). In addition to all the above factors, autonomous driving style is also expected to have an influence (Paddeu et al., 2020a), and so it is important to understand if the difference in driving style might have a positive or negative impact on people's perceived comfort, and if it is line with expectations (Elbanhawi et al., 2015). Also, considering that the expectations are that drivers could make better use of time when on board an AV compared with car travel (e.g. undertaking activities other than driving), Diels et al. (2017) wonder if autonomously-driven vehicles will really offer a sufficiently comfortable experience as to permit a wider range of activities than currently enjoyed by car passengers, or if an increase in motion sickness with a related decreased level of comfort could actually limit activities, considering that the results of their study suggest that motion sickness might be experienced by most people (50%-75%). Furthermore, previous studies have mainly focused on exploring the comfort of drivers rather than passengers, whereas with SAVs the focus will move to passengers' comfort, as none of the users will drive.

Another important factor that might influence adoption is the perceived saving of travel time. SAVs are expected to offer the opportunity to develop a range of activities during the ride (e.g. reading, listening to the music, watching videos), which might reduce the disutility when travelling, as in practice the time invested in those other activities is no longer regarded as being exclusively spent on travel, in which case the willingness to pay for saving travel time would be expected to diminish (Kolarova et al., 2016). It is therefore important to understand what kind of impact the implementation of SAVs would have on travel behaviour and mode choice.

In summary, the literature offers many studies of AV acceptance and adoption, whereas studies of SAVs are limited. Most such studies are based on task choice exercises (e.g. stated preference - SP) within online surveys that explore people's preferences towards AVs and SAVs in hypothetical scenarios rather than actual experiences with AVs or SAVs in real environments. SAV user characteristics are also poorly understood, although it is suggested that people with limited car access may be attracted to SAVs (Fagnant and Kockelman, 2015). However, in general there is no empirical evidence to allow an a priori segmentation of SAV users. The paper therefore offers an innovative perspective through presenting the results of a SP experiment designed to investigate preferences towards SAVs before and after experiencing a ride in a shared fully-automated vehicle in a real (but constrained) environment.

The rest of the paper is organised as follows: Section 2 presents the methodology used to explore people's preferences towards SAVs and a description of data collection. Section 3 presents the results of our study. Finally, Section 4 presents the discussion and conclusions.

2. Methodology

2.1. The experiment

The experimental condition consisted of a ride in a four-seat electrically-powered fully-automated vehicle, in a closed area of car park at a large out-of-town shopping mall located to the north of the city of Bristol (UK) during January 2020. The vehicle was fully occupied by unfamiliar people (except for two runs when there were three travelling) in order to create a 'busy', shared travel environment. Half of the participants experienced the ride with a safety steward taking the place of a participant, in order to explore any potential differences in trust and perceived comfort resulting from having an 'authority' presence in the vehicle. Also, half of participants were travelling looking backwards and the other half looking forwards.

Participants were escorted to the trial site from the management offices of the mall before and after their ride. The route of each run corresponded approximately to a loop, but with some navigation round planted traffic 'islands', and lasted 4-5 minutes, during which a series of interactions were staged. These included actors walking in front of the shuttle or passing on an e-scooter to demonstrate the shuttle stopping, slowing down, or continuing at the same speed if the control software identified no risk of collision.

Participants were asked to take part in two surveys: one before the experience and one after. The two surveys took on average 10-15 minutes to complete and were administered on touchscreen tablets in a quiet meeting room in the mall. Each participant was asked to carry out a choice task that included a reference mode and three AV alternatives: (1) four-seat AV-taxi shared only with family or friends; (2) four-seat AV-taxi shared with strangers; (3) AV minibus with a capacity of 10-15 people shared with strangers. A survey instrument covering trust and comfort was also administered before and after the experience in order to allow a comparison between expectations and final perceptions. The sample (N=123) was balanced in terms of gender (49.6% males, 50.4% females) and all age groups were represented even though there was a slightly higher number of people aged 50-69 (mean age of 55 years). Most participants had a driving licence (93.5%). Additionally, 65.9% of the sample defined themselves as very frequent car users, and 24.4% of the sample as frequent or very frequent bus users.

2.2. The model

Data collected before and after the experiment were analysed by estimating an Integrated Choice Latent Variable (ICLV). ICLVs are often employed in transport research (Vij and Walker, 2016) to capture unexplained heterogeneity between respondents and to quantify the effect of attitudes on choice. Figure 1 shows the model framework.

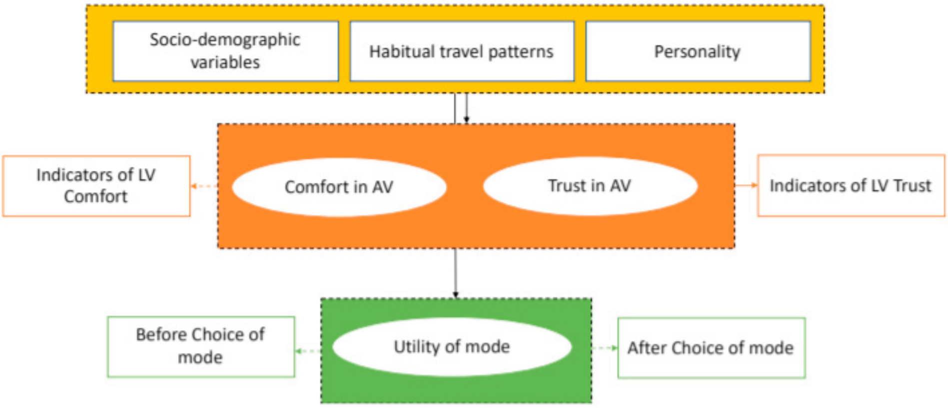

Figure 1. Model Framework

Structural model

Comfort (C) is defined as latent variable (LV) and is structured by using socio-demographic characteristics of the respondents. The variables included in the structural model are: gender (dummy variable with male as base), age (continuous variable), having a driver's license and frequency of bus trips. The structural equation of the LV is defined as a function of a deterministic part, which includes the observable person-specific variables ξ_n (e.g. gender, age, license, bus trips) and a random component (ν_n) (standard normal variate with mean 0 and standard deviation σ_v):

$$C_n = \gamma\xi_n + \nu_n \qquad \text{Eq.1}$$

where *Cn* is comfort for the individual *n* and γ are the coefficients to be estimated.

Measurement model

The measurement model is drawn upon five 7-point Likert scale questions as indicators and relates the latent variable *Comfort* with the indicators:

$$I_{C_n} = a + \lambda C_n + \eta_n \qquad \text{Eq.2}$$

where $I_{Comfort_n}$ is a vector of attitudes, λ is a matrix of model parameters measuring the sensitivities of the psychometric questions (indicators) to the latent variable and η_n is the stochastic term of the model (normally distributed with zero mean and standard deviation σ_η).

Choice model

An individual *n* assigns a utility *U* for mode option *i* (*i*= own car, autonomous taxi, shared autonomous taxi, autonomous bus), which is described in eq.3:

$$U_{in} = ASC_i + BX_{in} + \delta C_{in} + \varepsilon_{in} \qquad \text{Eq.3}$$

where ASC_i corresponds to the *Alternative-Specific Constants* to be estimated; X_{in} is the vector of the observed variables; *B* is the vector of the respective coefficients of the explanatory variables; C_n denotes the LV as specified in the structural equation above (Eq. (1)); δ is the coefficient of LV; and ε_{in} is the error term (noise variable) and it is normally distributed with zero mean and standard deviation σ_ε.

The likelihood function of the model to be maximised is defined as:

$$f(y_n, I_{C_n} | X_n; \gamma, B, \lambda, \delta) = \int P(y_n | C_{in}; B, \delta, \sigma_\varepsilon) f(I_{C_n} | C_n; \lambda, \sigma_\eta) f(C_n | \gamma, \sigma_v) \qquad \text{Eq.4}$$

The likelihood function is integrated over the distribution of B, λ, γ, δ. The model is estimated using pythonbiogeme (Bierlaire, 2016).

3. Results

3.1. Importance of comfort

The presence of the safety steward and the direction of travel were considered as independent variables to check if there was any difference in terms of respondents. However, the results of the between-subject ANOVA show that there is no main single or combined effect on comfort or trust. This means that the presence of the steward did not have any impact on people's comfort in the AV. This might be due to the fact that the travel speed was quite low (8 km/h), and it had a positive impact on perceived safety and trust, and then on comfort. So that having or not a safety steward on board did not make any difference. Similar to the presence or not of the safety steward, direction of travel (looking backwards/forwards) did not influence comfort or scores. The mean value for trust before the experiment was 4.4 (SD= 1.19), increasing to 5.5 (SD= 1.07) after the experiment. We asked participants to rate on a scale 1 (=not comfortable at all) to 7 (= extremely comfortable) a set of comfort attributes, and similarly to trust, scores increased after the experiment. The highest score was given to comfort with seating (+1.1, with 4.64 before – SD=1.17; 5.74 after – SD= 1.18); this is followed by comfort with vibration (+0.83, with 4.68 before – SD= 1.22; 5.51 after – SD= 1.35), comfort with noise (+0. 39, with 5.05 before – SD=1.36; 5.44 after – SD=1.49), comfort with temperature (+0.74, with 4.67 before – SD= 1.21; 5.41 after – SD= 1.41), comfort with acceleration/deceleration (+0.30, with 4.67 before – SD= 1.20; 4.97 after – SD= 1.43).

3.2. The models

The results of the two ICLV models (before/after the experiment) include structural model, measurement model and choice model results. In general, results show some variations on the structural model in the before and after models. Before the experiment socio-demographic characteristics that are associated with the perception of *Comfort* are: having a driver's license, being male and conducting a smaller number of bus trips per week. Age did not have a statistically significant effect. In contrast, when considering the structural model after the experiment, age becomes statistically significant and has a negative effect on structuring the *Comfort* LV: older people are less likely to score high in the Comfort indicators. On the other hand, the attributes of having a driver's license and respondent gender are not statistically significant. Women are less likely to report that they feel comfortable before the experiment, but this effect becomes statistically insignificant in the post-experimental model. Further, the frequency of bus trips becomes positive, meaning that the frequency of bus use is positively associated with the likelihood of a comfortable experience being reported and while higher frequency was negatively associated with comfort indicators before the experiment, higher frequency was positively associated with them after the experiment. This effect can be explained by frequent bus users indicating lower scores for comfort before experiencing the ride in the SAV, but their ratings changing positively after the experience. This is the variable with the greatest difference when comparing the before and after models. Regarding the measurement model results, all signs are in line with expectations.

Regarding the choice model, travel time and travel costs of all alternatives are negative and statistically significant in both before and after models. Waiting time, on the other hand, is mostly insignificant in both models, for all modes. The LV *Comfort* has a positive and significant effect on all autonomous modes of the choice set (taxi, shared taxi and bus) revealing that individuals who have self-reported as expecting to be more comfortable in the AV are more likely to choose one of the autonomous options in the experiment, both in the before and after models.

The analysis included also the calculation of value of time (VoT) for all modes in the before and after experiment settings. This was calculated as:

$$VoT_i = \frac{\beta_i}{\theta_i}$$

where β_i is the estimated coefficient for the travel time for each alternative i) and θ_i is the estimated coefficient for travel cost for each alternative i. We can calculate mode-specific values of time given that we use alternative specific coefficients for travel time and travel cost for each mode.

The initial VoT for own vehicle (car) was twice that of shared autonomous taxi, with exclusive autonomous taxi slightly lower than the shared option and autonomous bus around a fifth that of car. All showed an increase in VoT after the experience except shared autonomous taxi. The VoT for own vehicle (car) increases by 15.3% after the experiment. This probably indicates an increased valuation of the own vehicle utility compared to the AV options. Also, for AV taxi (e.g. exclusive used) the increased VoT is about 2€ per hour (+29.2% compared with the before survey), suggesting that participants' perceptions of AV taxis has positively changed after the experience. The VoT for AV bus also increased by 34.1% in the post-ride survey. On the other hand, results show a slightly decreased VoT for the Shared AV taxi. However, the difference is very small (-0.07%).

On the other hand, if we look at the before/after comparison of choice preferences, the most preferred mode before the experiment is the (own) car. This was followed by AV taxi, Shared AV taxi and AV bus. After the experiment, AV taxi becomes the most preferred choice, followed by Shared AV taxi, (own) car, and finally AV bus.

4. Discussion and conclusion

The results of this study show that the presence of a safety steward on board did not have any influence on people's trust and comfort scores. This might have been influenced by the low travel speed, which made participants feel safe and so they trusted the SAV and felt comfortable on board, as trust and comfort scores quite high up the scale were selected. Also, the direction of travel (e.g. looking backwards/forwards) did not have a significant effect on trust and comfort. This is in line with the results of Paddeu et al. (2020) for comfort, but in contrast with their results for trust. In fact, in the first experiment carried out by Paddeu et al. (2020) (i.e. an earlier experiment to the one reported here, but in the same project), they found that the direction of face when travelling on board the SAV had a significant main effect on trust, with trust scores when facing forwards being higher than when facing backwards. However, the earlier experiment in part involved a higher speed of travel, whilst previous studies found that low speed has a positive effect on perceived safety and trust (Bekhor et al., 2003; Rodríguez, 2017; Paddeu et al., 2020), so the absolute speed may have been insufficient to trigger the trust difference. However, comfort scores increased after the ride, suggesting that the low speed at least did not have a negative effect on comfort. This is in contrast with the results of the study carried out by Nordhoff et al. (2019), who found that comfort in SAVs is negatively influenced by absolute low speed.

A great number of published studies exploring people's perceptions and attitudes towards SAVs and willingness to pay to use them imply the use of SP and choice modelling (Gkartzonikas and Gkritza, 2019). However, these studies are based on the results of online surveys addressed to people with no real direct experience with AVs or SAVs. The novelty of the present study was the delivery of paired pre and post surveys to people who had an experience with a SAV in a non-simulated environment. Women had lower expectations in terms of expected comfort on the SAV, but after the experience they showed a more positive (significant) attitude. We can say the same about bus users, who turned their lower expectations into a more positive perception of comfort after the experience in the SAV. This might be because bus users expected the SAV to be less comfortable than (or as comfortable as) a bus, whereas after the experience they realised the inside part of the SAV was quite spacious and allowed for four people to travel comfortably; an experience sometimes in contrast with bus travel, where the availability of clean and soft seats is not guaranteed, and the internal space can be crowded causing increased anxiety (Cheng, 2010) and stress (Lundberg, 1976; Mohd Mahudin et al., 2011). Previous studies (Clayton et al., 2020) identified bus users as potential SAV users, probably because they already perceive the fact of not driving whilst on public transport as an advantage compared with driving a car (Beirão and Cabral, 2007), and of course some (few in the case of the present study) would not have a car option.

Considering the methodology applied, in the SP exercise, the cost of each alternative is provided in the related utility function. However, the results from the model show that the travel cost parameters are not significant. This might be due to the size of the sample (i.e. N= 123 individuals is quite small to allow the model to perform well) that might have had a negative impact on the variance. The results of the VoT indicate that there is some change before and after the experiment. In general, VoT increases after the experiment for all alternatives, apart from Shared AV-taxi. The analysis indicates that, following exposure to the SAV, participants are willing to spend more money to spend a given amount of time in a car, in an AV taxi and AV bus, and slightly less for the given time in an AV shared taxi. This is supported by the ASCs of the model, which give an indication of preferences, if other factors in the model are ignored. However, these findings are not harmonious with the choice preference results, where it is observed that the experience resulted in participants' evaluations of some of the AV options exceeding those of the mode they would apparently pay most for; the private car. In particular, AV taxi and Shared AV taxi preferences increased respectively by +4.6% and 1.6%, moving these alternatives from second and third place (before the experiment) to first and second place (after the experiment) in the preferences ranking. Interestingly, the (own) car, which was the most preferred option before the experiment, shows a 2.4 percentage-point fall in preference after the experience, and AV bus 3.8 percentage-points. This might suggest that participants perceived AV taxi and Shared AV taxi as more convenient than car and AV bus; as more flexible options in terms of accessibility and costs. However, this does not fully account for the differences in value subscribed by the VoT measures. Another possible explanation is that a novelty effect was in play, with participants' general evaluations influenced by the positivity and prestige society places on road transport automation, whilst the VoT experiment, grounded in specific example journeys, yielded more practical evaluations of options.

In conclusion, the approach sought to overcome the limitations of SP experiments by providing participants with a SAV experience, rather than a hypothetical scenario. The results of the study indicate that service attributes (such as travel time, waiting time, travel cost) examined in this context can have a significant impact on factors associated with SAV acceptance and adoption. However, the operational conditions of the experiment (e.g. slow speed, constrained route) also introduced limitations on the degree of realism of the experience. Nonetheless, the study represents a novel contribution to the literature on people's preferences towards future mobility options, which will be designed mainly considering passenger's expectations and needs. Further research is necessary to understand better how the changes in before/after VoT relate to the changed rank order of preferences for the four modes. It would also be of interest to exploring other latent variables (capturing trust or other attitudes towards SAV) or adopting alternative methods to explore heterogeneity among different users to investigate segmentation of potential SAV users.

Acknowledgements

The research reported in this paper was funded by Innovate UK (grant reference 103288) and undertaken as part of the CAPRI Project. The authors are grateful to members of the CAPRI Consortium for making the automated vehicle trial possible, in particular Westfield Technology Group, and AECOM Ltd, and to the owners and management of the Cribbs Causeway Shopping Mall. The authors benefitted from membership of the European Commission-funded Cost Action (CA16222) 'Wider Impacts and Scenario Evaluation of Autonomous and Connected Transport' network in developing the paper. The authors also thank our participants for their time.

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