Autonomous Vehicles: Who will use them, and will they share?

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Abstract
The advent of road transport automation is suggested to be one of four key technological transitions that could amount to a major transformation in mobility practices. Specifically, fully Automated Vehicles (AVs) might replace the current private car owner user model with fleets of on-demand synchronously-shared automated taxis. However, significant barriers to this vision becoming the norm remain. This paper examines two critical user-acceptance aspects of the transition: willingness to adopt AVs, and willingness to share an AV with others, particularly strangers. Our novel survey (n = 899) included a choice experiment featuring four future full automation transport services (private, synchronously/ asynchronously shared, and public). Cluster analysis examined respondents' preferences and their demographic and psychosocial characteristics. We uncover significant uncertainty about willingness to adopt automation and sharing, and important differences between clusters within our sample. For example, under 50% of participants report willingness to use an AV over their normal mode, or would prefer an automated option to a current human-driven option. Our findings raise critical questions for policymakers and transport authorities. Not least, how can AV technologies help realise the environmental and social benefits of widespread vehicle sharing in a context of a travelling public that still prefers its privacy on-the-move?

1 Introduction

Autonomous Vehicle technologies have become the subject of substantial research attention in recent years, and have been examined from a wide range of perspectives. As is considered in further detail below, a number of studies have investigated public perception of autonomous modes of transport, however a gap remains in our understanding of how different groups and segments within the population view these new technologies, and in particular, whether they would be willing to use them in a shared service environment. Hence, the aim of our study was to investigate people's willingness to use and share AVs, with a focus on identifying different possible groups of future users and non-users for different service scenarios for exclusively-used and shared modes. Through our analysis we successfully identify different groups of people who would and would not use these different notional AV modes, based on their demographic and psychosocial characteristics.

The remainder of this section reviews relevant existing literature around the potential implications of adopting highly-automated vehicles, adoption preferences, and sharing preferences.

1.1 Willingness to use automated road transport services

Automated and Autonomous Vehicle (AV) technologies are receiving considerable attention from transport specialists, but they have also generated significant interest in transport matters amongst politicians, the media and the general public. Great enthusiasm emerged in the mid-2010s around the possible investment opportunities and transport system efficiency benefits that might derive from widespread adoption of highly-automated vehicles, as part of a 'smart mobility revolution' that would also involve full electrification of the vehicle fleet, widespread simultaneous sharing of vehicles (i.e. ridesharing, car-pooling), and the routine application of digital technologies to transform traveller information, service booking, ticketing, and modal integration both within journeys and across a person's 'mobility style' (Parkhurst & Seedhouse, 2019). However, as Parkhurst and Seedhouse summarise, whilst all four transitions involve considerable further technical and implementation barriers, user acceptance of the practices of automation and the simultaneous sharing of vehicles with strangers may also prove to be major psychological and social barriers to this vision becoming reality. Of these, it is possible that adoption, as has been seen with other technologies, including in the transport sector, is partly a matter of exposure and experience, but a significant increase in vehicle sharing would only be expected if apparently strongly-formed sociocultural attitudes and practices change (Whittle *et al.*, 2019).

Notwithstanding these barriers, an increase in vehicle ridership through sharing potentially offers important road space, energy efficiency and greenhouse gas emissions benefits. Similarly, failure to achieve these efficiencies in the context of traffic growth would increase congestion, pressure on energy resources, and

run counter to international climate change objectives. The present article therefore provides novel analyses to inform the policy debate on whether and how road transport automation should be implemented.

1.2 Existing evidence of willingness to adopt automated road vehicles

Willingness-to-use (WTU) AVs has been the subject of a number of studies, which have explored the issue from demographic, attitudinal, behavioural, and trip characteristic perspectives. Becker and Axhausen (2017) provide a thorough review of the existing studies in this area. The findings of these studies paint a complex and sometimes contradictory picture of people's WTU AVs, and the factors that are important in this. Some general trends are evident amongst the studies. Men appear to be more positively disposed towards AVs than women, and younger people have greater intention to use these technologies than older people, although some studies dispute this (for example, see: Nordhoff *et al.*, 2018). People that currently own and/or drive a vehicle, and that have exposure to some form of AV assistance features are also most positive (Becker and Axhausen, 2017).

Becker and Axhausen (2017) note that there is a gap in knowledge in relation to the perceptions and attitudes of different segments of the population towards AVs, and this paper addresses this gap by including a cluster analysis to identify different user groups and the attributes of AV that they find the most important.

1.3 Implications of AV adoption with synchronous or asynchronous sharing

The use of the term 'sharing' in the mobility context can be ambiguous (Currie, 2018), with the key distinction for the purposes of the current analysis being whether individuals have exclusive use of a vehicle that will later be used by others in a *taxi* operation, so that the vehicle is asynchronously shared, or is used by individuals who are at least willing for other travellers to share all or part of the journey, with the likelihood that these travellers are unknown to each other. Examples of the latter type of service are ridesharing, ridesourcing or shared taxi.

Most existing studies of sharing in the context of automation have focused on asynchronously shared services; referred to in the present paper as Automated Taxi (AT) services. Synchronous sharing has been less studied, referred to here as Shared Automated Taxi (SAT) services.

These two types of sharing are very different in important ways. A critical element of an AV future that realises benefits related to traffic and congestion reduction is the shift away from the predominance of single-occupancy (private) vehicle use towards a model of shared use. Anderson *et al.* (2014) suggest that if private ownership and usage continues, AVs are most likely to generate a significant *increase* in personal Vehicle Miles Travelled (VMT). This is due to the efficiency gains of AVs (the opportunity to engage in activities whilst travelling, the removal of the need to find parking, safety improvements, and improvements in fuel efficiency) and the associated reductions in the marginal costs of car travel.

Therefore to achieve the most socially and environmentally desirable future, it is evident that an AV fleet should operate in a context of high levels of synchronous sharing. Otherwise, ATs might become responsible for increased kilometres travelled, moreover in small, less energy-efficient vehicles (Krueger *et al.*, 2016; Fagnant and Kockelman, 2018).

1.4 Willingness to share

Therefore, the big question central to the widespread success of synchronously shared AVs is this: "How willing are people to share a small vehicle (i.e. a car/taxi)?" More specifically, "how willing are people to share a small vehicle with others: potentially *strangers*?" And now in the AV context, this question is extended further to remove the driver (the "authority figure"), asking: "how willing are people to share a small vehicle with other people (possibly strangers) in a context in which there is no driver physically present?" Understanding this question is key to understanding the challenges faced by transport authorities, planners, and operators in introducing the more beneficial AV futures that widespread adoption of SATs within a network might create, in comparison to a persistence of the situation of private ownership and use.

There is a range of existing literature which has explored travellers' willingness to asynchronously share conventional vehicles in current Mobility as a Service (MaaS) contexts such as shared taxi schemes, car-sharing for work, and so on (see: Merat *et al.,* 2017). From a psycho-social perspective, several main determinants of people's willingness to engage in such schemes have been identified. These include demographic characteristics (gender, age, socio-economic status) (Vanoutrive *et al.*, 2012); an individual's personality (Roy, 2016); trip characteristics (purpose, length, time of day) (Malodia and Singla, 2016; Chowdhury and Ceder, 2016); and lastly, the qualities of the shared vehicle itself (make and model) (Kawgan-Kagan, 2015). There is a great deal of variation in the individual findings within these studies, which creates a mixed picture of the most important of consistent factors affecting willingness-to-share in conventional MaaS networks.

However, as has been established, to achieve the positive outcomes of a shift to AVs, it will be necessary to have vehicle sharing in which people *share the same vehicle with others on the same trip*, i.e. SAT (Fagnant and Kockelman, 2015; Greenblatt and Saxena, 2015; Greenblatt and Shaheen, 2015). A limited number of studies to-date have specifically examined this shared AV context; those which have identified a number of characteristics related to participants' perceptions of shared AV. Age is suggested to be an important factor in shared use. Results of an online survey carried out by Krueger *et al.* (2016) to investigate willingness to use ATs showed that individuals aged between 24 and 29 years old are relatively more likely to select the option AT with SAT. Conversely, respondents aged between 65 and 84 years old would not use AT or SAT. A survey of users of an SAT shuttle trial in Berlin-Schöneberg found that it was older people that expressed a higher intention to use the shuttle, but also rated the utility of the shuttles relative to their normal mode of travel more negatively (Nordhoff *et al.*, 2018). Dong *et al.* (2019) looked at sharing in the context of an AV bus, and similarly to Krueger *et al.* (2016), found that younger people were more willing to use this mode. Importantly, Dong *et al.*'s (2019) study also identified the importance of an authority figure in the vehicle, finding that two thirds of people were willing to use it when there was a conductor on board, but this dropped dramatically to just 13% of people when there was no "official" presence in the shared vehicle. This demonstrates that the social setting and perceptions of personal safety and comfort in the shared AV context are likely to be highly important in people's willingness to use these modes in future, particularly as they are first rolled out. Dong et al's study also found an influence of gender in perceptions of the AV bus, with men more likely to report being willing to use it than women. This has been supported by Wells and Wadud (2019), who found that women were more cautious of smaller shared vehicles than men. Wells and Wadud's research went further in identifying some psycho-social characteristics of people's sharing preferences. Extroverted people were more likely to be happy sharing a smaller vehicle with strangers, whilst more introverted people preferred larger vehicles. Another factor identified as important in a decision to use SATs was waiting time (Krueger *et al.*, 2016). Their study highlighted that AT and SAT were perceived as two distinct mobility options by their participants. This distinction suggests that the additional time a user might have to wait for an SAT versus a private-use AT could determine the attractiveness of such modes. Linked to this, service configurations and fares are critical determinants of SAT acceptance, particularly if ATs with SAT were to compete with ATs without SAT (Ibid). As is evident, the existing research suggests a mixture of demographic and service-based determinants of people's willingness to share.

In this crucial context of future AV sharing, this paper reports on a novel study which examines the service-based, demographic, and psycho-social determinants of people's willingness to use shared AVs. We establish clusters of possible future users and non-users of these new modes, to provide insight into people's preferences for different future AV service options. Importantly, our analysis brings together these service-based, demographic, and psycho-social factors through our identification of clusters of potential AV users and non-users. The following section describes our survey designed to explore people's willingness-to-use and willingness-to-share AVs in a range of future service options.

2 Methodology

The data collection involved 899 participants recruited to complete an online survey from the urban area of Bristol (UK) and its immediate hinterland (comprised by the administrative areas of Bristol City and South Gloucestershire). Potential participants were approached through an email invitation sent to the two local authority 'citizens' panels' (which are lists of local residents who have agreed to be contacted to participate in surveys relevant for the future development of the local area), one community group, and students of psychology and geography studying in the city. The latter two groups were included to balance the preponderance of older, longer-established households in the citizens' panels, with a view to constructing a broadly representative sample of the local population. The resultant demographic composition of the sample is detailed in Table 1, and a comparison to actual UK Office for National Statistics population estimates provided in Table 2 (BCC, 2019).

The survey sample has been compared to 2018 population estimates for local demographics in the West of England Combined Authority (WECA) area[1]. The age brackets from our study and the age brackets used in the population estimates do not match exactly, but it is nevertheless possible to make a broad comparison. In terms of age, the spread was similar in the middle age categories, whilst the survey had a higher proportion of participants in the oldest age ranges, and a lower proportion in the youngest, when compared to the regional population data. For gender, the proportion of men and women was split similarly

[1]The West of England Combined Authority area includes three Local Authority areas: Bath and North East Somerset, City of Bristol, and South Gloucestershire.

in the middle and older age ranges, but there were fewer men surveyed in the younger age ranges when compared to the regional data (NOMIS, 2020).

Table 1 - Sample gender and age

Age	Gender					
	Female		Male		Total	
	N	%	N	%	N	%
16-20	60	16.2	15	3.0	75	8.6
21-29	20	5.4	12	2.4	32	3.7
30-39	35	9.4	57	11.3	92	10.5
40-49	65	17.5	54	10.7	119	13.6
50-59	78	21.0	109	21.6	187	21.3
60-69	74	19.9	142	28.1	216	24.7
70+	38	10.2	111	22.0	149	17.0
Prefer not to say	1	0.3	5	1.0	6	0.7
Total*	371	100.0	505	100.0	876	100.0

**Missing values are not included in the total.*

Table 2 – WECA 2018 Population estimates by age and gender[2]

Age	Gender					
	Female		Male		Total	
	N	%	N	%	N	%
0-15	87,512	18.7	83,151	17.7	170,663	18.2
16-24	68,656	14.7	67,716	14.4	136,372	14.5
25-49	166,936	35.7	160,345	34.1	327,281	34.9
50-64	76,612	16.4	78,267	16.6	154,879	16.5
65+	67,770	14.5	81,190	17.2	148,960	15.9
Total	467,486	100.0	470,669	100.0	938,155	100.0

The survey comprised of three main sections:

- Part 1 involved a Stated Preference exercise to evaluate the acceptability of four AV modes as an alternative to their usual mode for a current regular intra-urban trip. Participants' usual mode was identified from their stated most frequent mode for a trip of this type.
- Part 2 sought information about participants' perceptions and attitudes towards automation and transport issues.
- Part 3 participants collected demographic data. The main questions related to basic characteristics (gender, age, education), current travel habits (usual mode, driving licence holding), and disability/mobility impairment questions (mobility limitations by mode, blind/partially sighted, use of mobility scooter, disabled person's parking permit).

2.1 Stated Preference Exercise

The SP followed a Contingent Valuation (CV) method. CV is a form of stated response experiment that examines participants' *general* WTP for the entire "good" under examination (here a journey in each of four AV service options). CV approaches have similarities to but are distinct from other forms of stated response experiment, such as Discrete Choice Experiments (DCE) – or choice modelling experiments – which can provide a valuation of *individual attributes* or *characteristics* of a good (Competition Commission, 2010; Pearce *et al.*, 2002; Bateman *et al.*, 2002).

[2]*Source: ONS 2018 Mid-Year Population Estimates. Crown Copyright.*

Table 3 - Future AV service options used in Stated Preference exercise

Scenario[3]	Description
1. AV Car	An AV that is personally owned in a similar way to a conventional car. The owner has responsibility for the costs of purchase and operation of the vehicle. The vehicle is available to the owner whenever they require, and is for private use.
2. Automated Taxi	An AV that is not owned by the traveller, but instead operates like a conventional taxi, in that people book it for private hire and have exclusive use of the vehicle during their journey.
3. Shared Automated Taxi	An AV that is not owned by the traveller, but instead operates as a shared-taxi service. This is a relatively small vehicle (~6-10 seats) that people will share with a number of other passengers travelling to similar destinations.
4. AV Bus	An AV that is not owned by the traveller, but instead operates like a conventional bus service, in that it follows set routes, has designated stops, and follows an approximate timetable. This is a relatively large vehicle that people will share with other passengers using the same route.

2.2 Scenario design method

The design of the survey instrument has similarities to the approach taken by Steck *et al.* (2018). It was important to try to create a comparison that was as "real" or "relatable" as possible for participants, to try to overcome the challenges of visualising a future automated mode that might vary in significant ways from previous travel experiences.

The aim of the experiment in line with our methodological approach was to create a realistic scenario for participants based on a familiar urban journey that they regularly make, and then to present them with AV alternatives to this relatable scenario.

Therefore, in the opening questions participants were asked about their normal mode of transport for a typical urban trip, and the approximate distance band of this trip (as above). Dependent on these responses they were directed to AV scenarios which compared their normal mode to an AV alternative with attributes matched to their typical trip distance for that type of normal urban trip.

The values for cost-per-unit-distance travelled for current modes were calculated as follows:

- Private car user cost per mile was calculated from national figures for car ownership and maintenance (RAC, 2014a, 2014b),
- Average taxi fares were established from meter rates published by the local authority (Bristol City Council, 2013)
- Bus fares were established applying the zonal fare structure of the dominant (80%+ market share) local bus company (First Bus, 2018).

There were no equivalents to the shared taxi service operating in the Bristol area (and virtually none in the UK) at the time of study, so this did not need to be offered as a current option.

i) The **null scenario** (i.e. the "normal" or current mode to which AV would be compared) was made as representative of people's daily travel experiences as possible. This was achieved by asking people first to think of a regular journey that they made which began and finished within the same urban area (i.e. was an urban journey). Once people had decided upon this, they were asked to answer questions on the basic characteristics of this journey: what mode it used (car, taxi, bus, bicycle, walking), and *approximately* how long it was (1.5 miles (short), 3 miles (medium), 6 miles (longer)). Attributes were calculated for these varying lengths by each of the five null modes (car, taxi, bus bicycle, walking), with the man variables being cost (based on the parameters identified above) and journey time. Characteristics of the trip in each typical scenario were then determined. Finally, a generic picture of the mode was included with the description and price.

ii) The four **AV service options** were created and given details based on *realistic* current predictions of what a future example of this might be like. These manufactured details mirrored the categories of characteristics given to the null mode, so that participants could easily compare and contrast between the two different options. A generic photo was provided to represent as far as possible the intended attributes of the AV service offer. From the null scenarios we calculated different attributes (cost, journey

[3] In the survey, we used the terminology "Driverless Vehicles" and "DV" as this is more descriptive and understandable for the general public than "Autonomous Vehicles", "Automated Vehicles" or "AV".

time) for the different trip lengths, however, each participant compared all four AV alternatives for only one length of trip, dependent on what they had identified as a "typical" urban trip for themselves in the opening questions.

Both of the above elements were combined into a tabular format (see: Figure 1) and presented to participants. Each participant was shown the four AV comparison scenarios with attributes for the length of journey they had indicated in the scenario-setting questions. First participants were asked to compare the current and AV options, and state if they would be willing to use the AV option. If they were not willing to use the AV option, the response was recorded as not accepted, and the next question presented. If they were willing to use the AV option, an open-ended elicitation was activated seeking a value the respondent would be willing to pay for that option; to be expressed in British pounds and pence. In order to promote realistic estimation, participants were not questioned in respect of modes they had indicated they would not consider using. These values were combined into a scale variable at the analysis stage, and per-mile values were calculated to allow direct comparison across the participants' different urban journey lengths.

Figure 1 - Example of SP experiment table for normal car vs Shared AV (SAT) (3-mile trip)

	Car	Shared-DV
		
Ownership and cost	You own it and pay up-front and on-going costs	You pay for the journeys you make via the web or a smartcard
Sharing	You have exclusive use of the vehicle	You share with other passengers
Journey Planning	You work out the route yourself	The vehicle works out the quickest route
Calling/booking	No need to call or book a vehicle	You order in real time or pre-book using the web on your smartphone or other device
Carrying out the journey	You drive yourself to your destination	The vehicle picks you up and drives you to your destination. It picks up other passengers too if they are not far from the route
Activity during journey	Talking to passengers, listening to music/radio, using hands-free	Same as car, plus reading, using phone or laptop, looking out of window, playing games, snoozing
Parking	You find and pay for parking	No parking or parking payment required
Journey time	12 minutes	15 minutes
Time taken to access vehicle at the beginning and end of the journey	5 minutes	
Journey cost *This is based on what the AA says that it costs to run an average car. It includes all costs: ownership, fuel, tax, and parking*	£1.75	*See question below*

2.3 Cluster analysis

A two-step cluster analysis was performed in order to identify and define different groups of people within the sample that have similar perceptions and/or demographic characteristics. This is useful in understanding the similarities and differences between different groups in the wider population, and also in providing insight into how these different groups might respond to AVs in the future.

The two-step method is an exploratory procedure designed to reveal groups (or clusters) within a dataset that would otherwise not be apparent. The authors chose this method because the algorithm employed by this procedure can handle both continuous and categorical variables, and large datasets, which would take a long time to compute with hierarchical cluster methods. The two-step cluster analysis consists of two steps: (1) firstly, a pre-clustering is run to identify grouping; (2) following this, hierarchical methods are run to define the final clusters.

SPSS software was used to conduct the analysis. The analysis identified homogeneous groups of cases without prior knowledge of the number of clusters or any other information about their composition. Cases represent objects to be clustered, and the variables represent attributes upon which the clustering is based. Cases have been randomly ordered to minimise order effects. The optimal number of clusters was then

automatically selected by comparing the values of a model-choice criterion across different clustering solutions.

3 Results and discussion

This section presents the survey results, starting with a discussion of participants' basic willingness to use AVs, before moving to look in more detail at people's attitudes towards shared vehicles in comparison to private vehicles.

3.1 Willingness to use the automated modes

Table 4 shows the proportions of people willing to use the four AV modes when presented with a comparison to their existing mode (the null scenario) in the SP exercise. Over half of all participants were not willing to use any of the AV alternatives. By a small margin, each of the modes that currently exists in human-driven version attracted slightly less than 50% acceptance, but the mode which is novel was rather lower: the Shared AV (SAT) option was the least popular AV mode by a substantial margin, with just 38.9% of people willing to use this. These results demonstrate that there was no consensus around the AV technologies amongst participants.

Table 4 - Participants' WTU AV service options

AV mode	Would use?	N	%
AV Car	Yes	411	49.3
	No	422	50.7
AT	Yes	396	47.5
	No	437	52.5
SAT	Yes	324	38.9
	No	509	61.1
AV Bus	Yes	407	48.9
	No	426	51.1

Table 5**Error! Not a valid bookmark self-reference.** and Table 6 show the analysis of participants ranking of the different service options. A Friedman Test was conducted to examine the patterns in the results in Table 6, and this finds a significant difference between the mean ranks of the different service options ($\chi^2 = 689.9$; $p < 0.01$). It is evident that people retain a strong preference for their current mode of travel 64.8% of people listed this as their first preference, with an additional 14.4% reporting it as their second (mean rank 1.82). In terms of preference for AVs, it is the private options which are the most preferred. AV Car is the second most preferred of the service options, behind current mode. 22.3% of participants listed this scenario as their first choice, and a further 34.1% as their second (mean rank 2.75). The other exclusive mode, AT, was third most preferred, slightly behind privately-owned AV (mean rank 3.15). Most striking however are the results for the two fully shared AV options (SAT and AV Bus). These were the least-preferred options by a significant margin. For the SAT, just 2.7% of people gave this as their first preference, and a further 10.3% as their second preference (mean rank 3.70); AV Bus was listed by 5.3% of people as their first choice, and 24.1% as their second. A high proportion of people listed this as their least-preferred mode (36.5% - mean rank 3.57). This result for AV Bus suggests something of a split in the results, with a high proportion of people reporting it as their last choice, but also a not dissimilar proportion reporting it as their second or first.

Table 5 - Participants' ranked preferences for their current normal mode and four automated modes

	Current mode		AV Car		AT		SAT		AV Bus	
	N	%	N	%	N	%	N	%	N	%
First preference	544	64.8	176	22.3	55	7.1	21	2.7	40	5.3
Second preference	121	14.4	269	34.1	128	16.6	79	10.3	182	24.1
Third preference	68	8.1	84	10.6	308	39.8	197	25.7	114	15.1
Fourth preference	46	5.5	77	9.7	205	26.5	290	37.8	144	19.0
Last preference	60	7.2	184	23.3	77	10.0	180	23.5	276	36.5
Total	839	100	790	100	773	100	767	100	756	100

Table 6 - Descriptive statistics of ranked preferences

	N	Mean rank	Percentiles		
			25th	50th (Median)	75th
Current mode	756	1.82	1	1	2
AV Car	756	2.75	2	2	4
AV Taxi	756	3.15	3	3	4
Shared AV	756	3.70	3	4	4
AV Bus	756	3.57	2	4	5

This ranking analysis demonstrates that familiarity is an important factor in people's current preferences for future transport service options, and also that in a future AV context, privacy is much preferred over sharing.

Table 7 shows analysis from a survey question exploring people's stated reasons for a general preference of an AV or non-AV driving experience. This provides useful context to understand the main factors that people focus on in relation to different preferences. Table 7 first demonstrates that the majority (59.1%) of participants preferred the option to drive themselves rather than being driven (40.9%). The most common reasons for preferring the non-AV option were 'control' (66.9%), 'safety' (51.2%), 'convenience' (47.8%), and the 'driving experience' itself (34.8%). Conversely, the most common reasons listed amongst people preferring the private AV option were 'convenience' (62.6%), 'activities during journey' (54.6%), and 'safety' (42.1%).

This demonstrates that a large proportion of travellers in each category are conceptualising the two options differently, but around the same notions of 'safety' and 'convenience' – this being split between one group that views safety and convenience as elements of the act of driving themselves, and a second which regards safety and convenience as being driven by an AV. Zmud *et al.* (2016) identified this safety dichotomy in their study, and it is interesting here to see that convenience is another feature of the experience that different groups are conceptualising in opposite ways.

Moreover, these results show an important split in the positive psychological experiences people have of travel. The group that would prefer to drive themselves place great value on feelings of *control* over their travel. This is something identified extensively in existing literature related to the psychological elements of driving and car travel (for example: Parkhurst, Kenny and Goodwin, 1992; Gardner and Abraham, 2007; Gatersleben, 2007). Conversely, the group that would prefer an AV to drive them do not generally desire control, but instead place a high value on the *activities that they can do during a journey*. Travel-time activity has also been identified as having positive value for travellers, in particular when a person does not have to be in control of the vehicle, and so is freer to do more (for example: Lyons *et al.*; 2013; Clayton *et al.*, 2017).

Table 7 - Participants' reasons for preferring AV or non-AV car

Reason(s)	Preference			
	Driving myself in a car (59.1%)		Being driven (40.9%)	
	N	%	N	%
Safety	271	51.2	154	42.1
Control	354	66.9	27	7.4
Convenience	253	47.8	229	62.6
Driving experience	184	34.8	75	20.5
Activities during journey	35	6.6	200	54.6
Other	34	6.4	39	10.7

3.2 Willingness to share automated modes

In the survey, people were asked to select cost values to give more information about their preferences, as cost will be an important factor in decision making. Table 8 presents the averages of the cost values people

selected for the different AV service options[4]. These values are used in this paper to provide additional insight to the question of willingness to use and willingness to share AV. In the case of the three AV options with an existing non-AV equivalent (AV Car, AV Taxi (AT), and AV Bus), additional rows have been included at the bottom of the table to show the calculated costs per-mile for non-AV modes given to participants in the survey, to provide a realistic point of reference for participants when making a decision about the AV alternative.

It should be noted that the per-mile values for non-AV equivalents presented in Table 8 are those that were presented to people in the different modal contexts of the survey (for example, people who chose 'car' as their normal mode were presented with the car figure, 'taxi' with taxi, etc.). Therefore, participants will have seen only one of these non-AV values, dependent on their route through the survey. The analysis of these tables is focussed on a general comparison of all participants' journey cost values to the values of these non-AV modes.

People gave the highest values for an AV Taxi (AT) scenario (£0.97/mile), in which they have private use of an AV for a particular trip. It is interesting to note that this is similar to the $1.00 per-mile price for a shared AV accepted by participants in the study by Bansal *et al.* (2016). Next highest is for the AV Car scenario, in which the average value given was £0.66/mile. For Shared AV (SAT), participants on average gave lower values per-mile than for a private car, with a mean of £0.59. Finally, the per-mile figure for AV Bus was substantially lower, at £0.47. This shows that of the four future AV service options, in which two are private modes and two are shared modes, participants reported, on average, higher values for the two private modes, and lower for the two shared modes. Specifically comparing AV Car with Shared AV (SAT), where the mean averages are quite close, looking at the standard deviations of the distributions, AV Car has a lower standard deviation (0.25) than Shared AV (SAT) (0.29). This demonstrates that the data for Shared AV (SAT) are more widely distributed than those of AV Car. This suggests that, collectively, there is a broader range of views towards what it is appropriate to pay for a Shared AV (SAT) than there is towards AV Car.

Table 8 - Per-mile journey cost values for AV service options with reference to costs per-mile for non-AV equivalents

Willingness to pay for an AV scenario				
	AV Car (£/mile)	**AV Taxi (£/mile)**	**Shared AV (£/mile)**	**AV Bus (£/mile)**
Mean	0.66	0.97	0.59	0.47
Median	0.67	0.83	0.58	0.50
Mode	0.67	0.67	0.67	0.67
Minimum	0.00	0.00	0.00	0.00
Maximum	1.33	3.00	1.33	1.00
Std. Deviation	0.25	0.57	0.29	0.24
Experiment values calculated for non-AV modes				
	Non-AV Car (£/mile)	**Non-AV Taxi (£/mile)**	**Shared vehicle**	**Non-AV Bus (£/mile)**
Value given for non-AV equivalent [£/mile]	**0.59**	**2.81**	***N/A*[a]**	**0.53**

[a]*Due to the lack of an existing real-world shared vehicle system in the study area, participants were unlikely to have experience of such a system. Therefore, this was not an option provided to people as a non-AV mode for comparison, and no reference value for trips by this mode was calculated.*

[4] *Note: Outliers have been excluded in this analysis. For AV Car, a number of participants had entered extreme £/mile values which can be attributed to a misunderstanding of the question, with people entering values for the price of the vehicle as opposed to that specific trip. These values were identified and removed. A boxplot was then produced in SPSS to identify outliers for AV-Taxi, Shared-AV, and AV-Bus, and all the extreme values were removed. In particular, with respect to the different AV modes: 37 extreme values (> £1.33/mile) were excluded from AV car; 33 extreme values (>=1.33 £/mile) where excluded from AV bus; 35 extreme values (>=3.33 £/mile) were excluded from AV taxi; 35 extreme values (>=1.50 £/mile) were excluded from Shared-AV.*

Discussion above identifies that people are placing a premium on privacy[5]: by a substantial margin, the AV scenario with the smallest proportion of people willing to use it at all was Shared AV (SAT) (38.9% - Table 4), Shared AV was participants' lowest-ranked preference (mean rank: 3.70/5), and both of the private occupancy AV service options were valued more highly per-mile than the shared options. Amongst people who were willing to use an AV, the highest-valued AV scenario was AV Taxi (AT), which was given a mean per-mile value of £0.31 higher than the next highest (AV Car). This suggests that, in future, travellers would be willing to spend more to have private use of a vehicle in an on-demand system. The difference between AV Car and Shared AV (SAT) was smaller, however, with AV Car being valued at £0.07 more per-mile on average. In this context then, people might be encouraged to switch from individual vehicle ownership to use of a SAT AV system if the price and service offering can be made competitive.

3.3 Demographic and social components of willingness to share

Considering demographic characteristics, there was no significant gender effect on willingness to use a SAT AV scenario. There was a small effect for journey purpose. The survey found that a higher proportion of people who travel for business reasons would use a Shared AV (SAT) (43.2%) than the sample more generally. Conversely, a very high percentage of participants who travel for educational reasons would not use this option (70.5%). There is a statistically significant relationship between age and willingness to use the Shared AV scenario. High proportions of younger (16-20 years old) and older (70+ years old) people would not use Shared AV (SAT) (61.6% and 72.3% respectively), whereas by contrast 56.7% of people aged 20-29 years old would use it ($p = 0.005$). It is interesting to see the split in the popularity of AV options between youngest age category (16-20) and the next youngest (20-29). Potentially there is an issue of experience here, with the older-younger group having had more time to have experiences of independent travel than the youngest group. Further investigation of this age divide is warranted. Furthermore, there is a significant association ($p = 0.012$) with primary transport mode. Less than 40% of car users would use Shared AV (SAT), most cyclists would not use Shared AV (SAT) (70.9% No), while bus users are split into two main groups (50.7% No; 49.3% Yes). The significant link between primary mode and AV preference is important, as it suggests aversion to shared modes amongst a high proportion of current drivers and cyclists.

The survey included a section to test whether a person's social disposition is an important element of their willingness to use AV in SAT scenario. Table 9 presents an overview of a cross-tabulation of people's valuation of AV against their reported social disposition. The results show a statistically significant relationship between people's agreement/disagreement with a statement about their social disposition *("I do not mind interacting with people I do not know"*) and their valuation of a trip in an AV Car in a future scenario. In general, Table 9 shows that higher proportions of people who do not mind interacting with strangers are prepared to pay more for AV Car than people who do not like interacting with strangers, in comparison to a non-AV mode. Specifically, a significantly higher proportion of people that reported being happy interacting with strangers also reported being happy to pay more for an AV Car when compared to people that feel less comfortable with this social contact (49.1%). This result was statistically significant ($p = 0.01$). The result for AV Bus and AV Taxi (AT) compared to their non-AV equivalents were not statistically significant.

Table 9 - Cross-tabulation of WTP for AV/non-AV with social disposition

	Statement: "I do not mind interacting with people I do not know"						
	Strongly agree/ agree		**Neither agree nor disagree**		**Disagree/ strongly disagree**		
	N	**%**	**N**	**%**	**N**	**%**	**Sig.**
Higher value for AV Car than non-AV Car	41	30.1	52	38.2	43	31.6	0.01
Lower value for AV Car than non-AV Car	82	49.1	54	32.3	31	18.6	
Total	123	40.6	106	35.0	74	24.4	

Further analysis was conducted looking at relationships between social disposition and people's WTU AVs in the different service options. Of the four service options, the only significant result came in people's

[5] *It should be acknowledged that the scenarios were not and could not be identical for everything other than the presence of another person. There were also some differences in service quality that should be kept in mind when interpreting these findings.*

responses to the Shared AV (SAT) option, in which a significantly higher proportion of people that are comfortable interacting with strangers were willing to use a shared AV in this scenario when compared to people that do not like these social interactions (p = 0.01) (Table 10).

Table 10 - Cross-tabulation of WTU Shared AV (SAT) with social disposition

	Statement: "I do not mind interacting with people I do not know"						
	Strongly agree/ agree		**Neither agree nor disagree**		**Disagree/ strongly disagree**		
	N	**%**	**N**	**%**	**N**	**%**	**Sig.**
Would not use Shared AV (SAT)	217	42.6	149	29.3	143	28.1	
Would use Shared AV (SAT)	165	51.0	100	30.9	59	18.2	0.01
Total	382	45.9	249	29.9	202	24.3	

These findings confirm a psycho-social element to people's perceptions of AV, which, interestingly, seems to have an effect more broadly than simply upon people's WTP for a shared mode such as a shared taxi or the bus. A significantly higher proportion of people that feel comfortable interacting with strangers were willing to use a shared AV (as might be expected), but also gave higher valuations for a private AV compared to a non-AV private car.

In considering options for directing and developing AV future service options it is therefore clearly important to take into account people's social disposition, and the effects this can have on their perceptions of the available options and their possible purchasing decisions.

Our results showed no relationship between WTU Shared AV (SAT) and level of education or job occupation, likewise there is no statistically significant association between disabled people and willingness to use Shared AV (SAT). However, in this case there is a higher percentage of disabled people (62.3%) who would not use Shared AV (SAT). This is in line with the rest of the sample, which showed a lower positive attitude to Shared AV (SAT) rather than to the other types of AV transport.

3.4 Cluster analysis of willingness to use and willingness to share

It is important to note at the outset of this section that no explanatory clusters were found when an analysis was conducted of people's WTU AV Car (i.e. distinct groups of people that would vs. distinct groups of people that would not use this). It appears that WTU is generally distributed across socio-demographic and broader travel characteristics. The analysis did however produce meaningful clusters *within* these two groups, and it is these that are presented here.

Different combinations of variables were considered to perform four cluster analyses (CA), which consider the characteristics of the groups of people WTU and not WTU AV Car (CA1 and CA2), and the characteristics of the groups according to people's preference for AVs or human drivers (AV Car - CA3 and all AV modes - CA4).

The characteristics of the clusters are described in Table 11. The first and second cluster analyses were based on a distinction between people who would use and people who would not use AV Car.

Amongst people who *would use* the AV Car scenario, an important finding is that it is possible to distinguish groups based around WTP. It is apparent that people with lower use of, or less access to, a car gave higher values compared to a second group that included a higher proportion of car users. This suggests a relationship between perceptions of AV and car availability, where previously none was found (Krueger *et al.*, 2016). The former, higher-paying group was comprised of a majority of females, a high proportion of bus users, and had people that enjoy being car passengers. The second, lower-paying group was comprised of a higher proportion of male car users and cyclists that enjoy driving and find commuting stressful and frustrating. This relates in part to Bansal and Kockelman's (2018) finding that more experienced drivers were willing to pay less for new vehicle technology. Our finding here is relevant because it implies that participants currently without access to a normal car place a higher value on the autonomous scenario than people that currently do have access. Our finding also has relevance in suggesting that there might be different values placed on different levels of automation by different groups. Our analysis identified that drivers who find commuting stressful and frustrating would use AVs but have placed a relatively lower value on it; one potential implication of this is that these drivers might benefit from something less than Level 5 automation (which was the level assumed in our study). The relative WTU of different levels of automation would be an important area for further research.

Table 11. Cluster analysis – Characteristics of groups

	Description	Results	
		Cluster 1 (C1)	**Cluster 2 (C2)**
Cluster Analysis 1 (CA1)	Only **people who would use AV Car** were selected for this analysis (n = 411). 384/411 included in final clusters (93.4%).	*22.14%* *N = 85*	*77.86%* *N = 299*
		On average **WTP per mile higher compared to C2 (mean=£1.61/mile)**. WTP more than the sample average per mile for AV Car. High proportion of **bus users**, with **provisional UK** driving licence or **no driving licence**. **Enjoy being car passengers**. Mainly **females**. All ages are included, but the **youngest** categories are mainly represented.	On average **WTP lower per mile compared to C1 (mean=£0.72/mile)**. WTP substantially more than the sample average per mile for AV Car. Especially **car users** and **cyclists** (together they represent 90%), They mainly hold a **regular UK driving licence**. **Enjoy driving**, and find **commuting** is '***stressful***' and '***frustrating***'. Mainly **males** and **older people**.
Cluster Analysis 2 (CA2)	Only **people who would not use an AV Car** were selected for this analysis (n = 422). 412/422 included in final clusters (97.6%).	*41.5%* *N = 171*	*58.5%* *N = 241*
		A relatively high proportion of **bus users** (35.7%), with **provisional UK** driving licence or **no driving licence**. The majority agree **there needs** to be a **reduction** in the numbers of **cars** on roads and **air pollution** is a **problem** for them. The majority w**ould not use AV taxis** or **AV cars**, they **would use AV buses** (53.8%). Both genders and all ages included, even though this cluster includes the majority of **younger people who would not use AV cars**.	The majority are **car users** (89.2%); 78.8% are **car drivers**. The majority **enjoy driving**, and find **commuting** is '***stressful***' and ***'frustrating'***. This cluster are **mainly males** (58.9%) and **older people**.

	Description	Results	
		Cluster 1 (C1)	**Cluster 2 (C2)**
Cluster Analysis 3 (CA3)	Focus on the difference between people who would either**:** **(1) Prefer driving themselves in a car** - or - **(2) Prefer being driven by Driverless Vehicle technology in a car**. 807/899 included in final clusters (89.8%).	*47.7%* *N = 385*	*52.3%* *N = 422*
		Would prefer driving themselves in a car (99.7%) because they **want to take '*control*'** (71.2%), **do not** place much **importance** in **doing '*activities during the journey'*** (4.4%), and find it is ***convenient*** (50.9%). This group are **mainly car drivers** (71.4%), they **enjoy driving**, and **would *not* be willing to give up personal car ownership** if they had access to a **shared Driverless Vehicle** system which was able to provide them with the same level of service as the car, for approximately the same price. The majority **would not use AV Taxi (AT)** (no: 76.8%), **AV Car** (no: 73%), **Shared AV (SAT)** (no: 83.4%), or **AV Bus** (no: 69.1%). All ages are included in this cluster. However, **younger people** (16-39 years old) are **less represented** than in C1. In general, people with no car are less represented in this cluster.	**Would prefer being driven by Driverless Vehicle technology in a car** (78%) because they can do '***activities during the journey***' (44.5%) and find it is ***convenient*** (57.3%). This group **are not concerned with having '*control*'** (17.3%) and **would be willing to give up personal car ownership** if they had access to a **shared Driverless Vehicle** system which was able to provide them with the same level of service as the car, for approximately the same price. They use **all modes of transport** and **some** of them **do not hold a driving licence**. The majority **would use AV Taxi (AT)** (69.91%), **AV Car** (69.7%), **Shared AV (SAT)** (59.7%), and **AV Bus** (65.2%). All ages are included into this cluster. However, there is a greater representation of **younger people** (16-39 years old) than in C2.

	Description	Results	
		Cluster 1 (C1)	**Cluster 2 (C2)**
Cluster Analysis 4 (CA4)	Focus on the difference between people who would either: **(1) Prefer being in a vehicle with a human driver** - or - **(2) Prefer being driven by AVs.** All modes (AV Car, AV Taxi (AT), Shared AV (SAT), AV Bus) considered. 798/899 included in final clusters (88.76%).	*51.9%* *N = 414*	*48.1%* *N = 384*
		The majority **would prefer driving themselves in a car** (93%) due to '***control***' (69.8%) and '***safety***' reasons (63.8%). The majority **would prefer** being in a **taxi** (88.5%) or on a **bus** (90.6%) **with human driver** because they perceive it as **safer**. The majority **would *not* be willing to give up personal car ownership if** they had access to a **shared Driverless Vehicle** system which was able to provide them with the same level of service as the car, for approximately the same price. The majority **would not use AV Taxi (AT)** (no: 78.9%), **AV Car** (no: 76%), **Shared AV (SAT)** (no: 82.8%), or **AV Bus** (no: 72.4%). All ages are included in this cluster.	The majority **would prefer being driven by an AV technology in a car** (72.5%) because they want to do '***activities during the journey***' (44.2%). The majority **would prefer being in an AV Taxi (AT)** (84.1%) or in an AV **Bus** (66.4%) because they perceive **AV Bus** is **convenient** (49.5%). The majority **would be willing to give up personal car ownership if** they had access to a **shared Driverless Vehicle** system which was able to provide them with the same level of service as the car, for approximately the same price. **The majority would use AV Taxi (AT)** (72.5%), **AV Car** (73.2%), **Shared AV (SAT)** (59.5%), or **AV Bus** (68.8%). All ages are included into this cluster.

Amongst people who *would not* use the AV Car scenario, there were again two clusters. In this analysis, the main distinguishing attributes were primary transport mode and the WTU AV Bus. The first cluster contained a majority of people that were bus users, held either no UK driving licence or only a provisional licence, and had a negative perception of the current numbers of cars on the road, and levels of air pollution. Interestingly, whilst this group would not use the AV Car scenario or the AV Taxi (AT) or Shared AV (SAT) service options, they *would* use the AV Bus scenario. The second group consisted mainly of male car users that enjoy driving. This demonstrates that there is a distinction between people that do not want to use an AV car because they currently do not use a car and have a negative opinion of the impacts of excessive private car use on society, and people that currently do use a car, are used to driving themselves, and largely enjoy the experience of doing so. This latter finding aligns with previous studies that have identified a passion for driving as having a negative association with perceptions of AV (Silberg *et al.*, 2013; Ipsos MORI, 2014).

The third and fourth cluster analyses were based on the preference for being in a human-driven car or in an AV Car, and more generally for being in human driven vehicles or AVs.

When the focus is on the preference for human-driven cars or AV Cars, a clear distinction can be made by age. It should be noted that people of all ages were included in both clusters, but in general, a higher proportion of younger people would prefer to be driven by an AV car, whilst a higher proportion of older people would prefer to drive themselves in a car. This is consistent with the previous findings from the literature that suggest younger people are more positively disposed to AV (Krueger *et al.*, 2016; Schoettle and Sivak, 2014, 2015; Seapine Software, 2014; Bansal *et al.*, 2016; Ipsos MORI, 2014; Power; 2012).

Our findings provide additional insight into the motivations behind this age divide: the younger, AV-positive cluster also contained a higher proportion of people that did not mind relinquishing control of the vehicle, and liked the opportunity to conduct activities during their time. The majority in this cluster would use a shared AV in a SAT scenario (confirming Krueger *et al.*'s (2016) finding). They were also open to giving up a car entirely for the option to use an AV MaaS-type scenario that could provide the same level of service. The older, driving-positive cluster contained a high proportion of people that like control over the driving experience, and are not concerned with being able to conduct activities during the journey. The majority of this group would not give up their car for an equivalent AV service. As discussed earlier, both of these clusters were distinguished by their perception of their choice as *convenient*, demonstrating that there is a demographic element to this attitude towards AV. Younger people see convenience as not having to drive themselves, whereas older people see the ability to drive oneself as being convenient for them.

However, when a preference for being in human-driven or driverless vehicles more generally was explored in the final cluster analysis (with car, taxi, and bus options included), there was not a strong characterisation in terms of socio-demographic characteristics, because both clusters include all ages and genders. The main distinction here was by perception of human-driven or autonomous vehicles. In general, human-driven vehicles are preferred because they are perceived as safer. In addition, people who prefer driving themselves in a car again indicated control as further reason for their preference. People in this cluster would not use any AV mode/scenario. In the second cluster, AVs were chosen because they allow activity during the journey and they are perceived as convenient. People in this cluster would, in general, use all AV modes/service options, including shared AV in a SAT scenario. These results show that people think AVs will provide a substantially different travel experience to the conventional car, giving them time for activities but removing the sensation of driving, which for some is a positive but for others is a negative.

4 Conclusions

It is one thing to posit and model a transport system which in theory could eliminate the need for the vast majority of vehicles in the urban transport system; it is quite another to plan and realise a system within a competitive urban transport market that the clear majority of travellers would choose to use. Hence, these findings related to the use of a future shared AV system are highly important. Autonomous technologies will, like all transport systems, need to be paid

for by someone. It seems likely that autonomous cars will be more expensive than human-driven cars, at least in the early stages of their rollout.

Our results show that, on average, respondents gave journey cost values over 10% higher than their current mode for the benefits of having a self-driving privately-owned vehicle (£0.66/mile). Participants gave the highest values for a shared autonomous taxi (£0.97/mile). Interestingly however, the average that people would pay for an autonomous taxi would be well under half the per-mile cost of a current, human-driven taxi. This reflects the fact that taxis are generally only used where essential: to make trips when no alternatives are available, such as late at night, or when a group is travelling together. Driverless taxis might be much cheaper to operate however, if there is no driver to pay, so they could become much more popular. The findings were similar for the bus: people would be willing to pay levels of bus fare slightly lower on average than current fares, but autonomous buses should be cheaper to operate per mile, so it would be possible to improve services for the same total expenditure. This could make buses more popular, and increase the relative attractiveness of this shared public mode, which could have positive environmental and social benefits from an associated reduction in private vehicle trips.

There are apparent challenges however in convincing the majority of people to choose a shared option over a non-shared option. Our results demonstrate that the shared vehicle AV option was the least popular of all the options, with most participants not currently willing to use this mode over their current non-AV mode used for normal urban journeys. Indeed, the two future service options which entail the highest levels of vehicle sharing (SAT AV and AV Bus) were less-preferred than the private-use service options by a statistically significant margin. Moreover, the two private AV options were both given higher average trip values than the two shared AV options. In an AV future, therefore, price is going to be a key component of encouraging a large-scale shift towards a shared AV scenario, with prices for sharing needing to offer a substantial cost-saving to offset the “privacy premium” that this study identifies.

Further to this, our results have explored the demographic and psycho-social components of perceptions of AV service options. Significantly higher proportions of people with a more “open” social disposition are willing to use and/or pay more for AVs in both shared and private contexts than are people of a more “reserved” disposition.

There are significant differences between people’s perceptions of future AV service options, and these differences can be grouped. People that reported that they would use AV cars in the future are split into two clusters: between people (with higher proportions of women and younger people) who currently do not have car access, and would pay more for access to AV in the future than the group who currently do have car access (more predominantly men and older people). People that would not consider using an AV-Car are split into two groups, one of which have limited (if any) experience of driving, and generally have a more negative perception of the car’s impact on society and the environment, and another which are passionate drivers and like the experience of driving too much to relinquish this to an automated system. General preferences for an AV car vs a non-AV car were split along age lines, with younger people being more positive about AVs and older people less so. Finally, it was the perceived qualities of AVs and non-AVs which distinguished the groups’ preferences for these. There is an important distinction between the experience that driving offers in terms of control and the experience that a future AV system might provide in terms of freedom to engage in activities, and people can be grouped around their perceptions of these two travel experiences. These issues would benefit from more in-depth psychological study to bring further insight into this important aspect of people’s preferences.

A shift towards an AT system that utilises sharing of both vehicles and trips vehicle presents an opportunity to tackle some of the negative environmental and social impacts of our current private-car-dominated transport systems. However, our results suggest significant challenges in encouraging this outcome over the current preference for private use of vehicles.

One of the main findings to emerge from our study is that the fundamental dilemmas of transport policy are modified but not fundamentally changed by automation: beyond the technological promises and possibilities of vehicle automation, a familiar question persists: *How do we encourage people to switch away from private vehicles to shared modes at a significant scale?*

There is an urgent need to intensify the debate about the future role of AVs in our transport networks. There is a possibility that the allure of a new technological fix to our current urban transport issues masks the potential for a continuation of, or even increase in, individual private vehicle use, as opposed to a large-scale shift towards greater shared use. Policymakers, transport authorities, transport providers, academics, and citizens must debate and collectively decide upon what is desirable in terms of sustainable shared systems of urban mobility, and then work to ensure that emergent AV systems support this future.

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