The social perspective on policy towards local shared autonomous vehicle services (LSAVS)

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Abstract

The transport policy discourse posits Shared Autonomous Vehicles (SAVs) as a more sustainable solution for the implementation of road automation technology. A successful implementation of SAV services strongly depends on being able to meet user's needs, as well as responding to their expectations. For this reason, the public has a central role in the definition of appropriate and realistic policies for the design, regulation and adoption of new automated mobility services. However, whilst there has been considerable attention to individuals' attitudes towards road transport automation, few have applied participatory or co-design methods to help define new SAV services. Moreover, most of the existing studies have also been hypothetical rather than examining vehicles in real service settings. This paper addresses these imbalances through reporting a two-stage research initiative. Initially a local shared automated vehicle service (LSAVS) concept was examined in a co-design workshop (Stage 1), leading to the development of a conceptual framework for social acceptance. This was then applied (Stage 2) in qualitative empirical research into the experiences of participants who rode in two different live prototype LSAVS. It was found that social considerations such as equity in access to mobility services, social inclusion, environmental protection, and concerns about control over interpersonal interactions emerged as strong acceptance factors within participants' construction of the conceptual services and responses to exposure to actual services. However, broad socio-political aspirations beyond transport policy were also important. It is concluded that achieving high levels of social acceptance where these utopian expectations meet commercial realities and public-sector constraints will be a major policy challenge facing any attempt to introduce an LSAVS with strong sustainable mobility credentials.

Keywords: Shared Autonomous Vehicle (SAV); AV trials; Social acceptance; Public acceptance; Co-design workshop.

1 Introduction

Shared Autonomous Vehicles (SAVs) are autonomous vehicles that can be either asynchronously shared (exclusively used by a travel party for a trip and then used exclusively by other parties) or synchronously shared (used simultaneously for at least part of the trip by separate travel parties which may be unacquainted) (Parkhurst and Seedhouse, 2019). The latter is sometimes termed Dynamic Ride Sharing (DRS) (Fagnant and Kockelman, 2015).

Synchronous sharing offers policy benefits through increased fleet utilisation and system efficiency (Krueger et al., 2016). Indeed, simulation studies (Payre and Diels, 2017; Xu et al., 2018) have emphasised that whether a transition to road transport automation can be consistent with sustainable mobility policy objectives is fundamentally dependent on the level of synchronous sharing, in order to avoid growth in traffic and congestion, which would arise due to falling user costs stimulating demand, as well as the empty running of vehicles relocating between trips, which would be much higher under an exclusive-use regime.

Specifically, scenario modelling has suggested that a synchronously shared and 'connected' (that is to say inter-communicating in order to operate collaboratively) AV fleet might require a vehicle fleet 90% smaller than one based on private cars, whereas an asynchronously-used fleet would still require nearly 80% of vehicles (International Transport Forum, 2015), with secondary implications for the scale of depot parking for such a fleet. Worryingly, the same authors did not find traffic or congestion reduction emerging from the synchronously shared scenario, whilst asynchronous use was found to double both. Indeed, due to being perceived as very convenient, SAVs might be used more often than currently available vehicles, increasing kilometres travelled in small, less energy efficient vehicles (Krueger et al., 2016; Fagnant and Kockelman, 2018), or generate an increased demand from those people who are too young to drive, or elderly people, or people with mobility issues (Fagnant and Kockelman, 2015). As well as a range of significant impacts on the environment, public health might deteriorate as vehicle travel becomes cheaper and faster, and so health costs rise due to reduced active travel and increased obesity rates (Fagnant and Kockelman, 2014, 2015). Nonetheless, even if not guaranteed, environmental benefits are far more likely to be achieved with synchronous sharing. Wadud, MacKenzie and Leiby (2016: 1) highlight the uncertainties here: "… automation might plausibly reduce road transport GHG emissions and energy use by nearly half – or nearly double them – depending on which effects come to dominate".

Whilst the policy imperative for synchronous sharing is clear, a number of doubts about it emerging as a significant travel behavioural option exist. First, even if the practical barriers to sharing the same vehicle reduce under automation, significant psychological barriers to sharing would remain (Merat et al., 2017). It is not clear how automation would reduce these psychological factors; they might even increase depending on how closely the vehicle is under remote surveillance from a trusted source, and how far a virtual authority presence can be successfully created in the vehicle. Second, other things being equal, synchronous sharing means privacy is lost or substantially curtailed through travelling with others, space per person availability falls, and the trip will be punctuated by the vehicle stopping to pick up/set down other passengers during the trip (Krueger et al., 2016). Lastly, Wadud and Mattioli (2019) note that if travel costs fall under automation then the premium for exclusive travel becomes less of a barrier. However, whilst these normative considerations are important, the outcomes of applying automated technologies depends critically on the type of vehicle(s) that comprise the fleet and their service niches. Therefore, in order to investigate policy implications, it is important to understand the specific context. Much of the existing literature discusses contexts that relate, either explicitly or implicitly, to the sharing of passenger car-type vehicles (4–8 seats) in mixed traffic on public roads, and often in urban areas (Wadud et al., 2016; Alonso-Mora et al., 2017; Fagnant and Kockelman, 2015). Other studies consider SAVs as autonomous shuttles running on specific routes at speeds which are lower than typical urban road limits and which can transport up to 8–10 passengers under the supervision of a steward on board the vehicle or observing from a remote-control room (Nordhoff et al., 2018). Nordhoff and colleagues conceived of SAVs as providing on-demand mobility services, travelling at a low speed (5 15 km/h), sharing space with pedestrians and cyclists, and occasionally with other vehicles. Speeds would–potentially be faster in parts of trip where more mode-segregated environments are available. The present paper is oriented to this definition;

it explores the potential benefits and applicability of LSAVS in specific use-cases which include sites with limited or no presence by motorised transport but frequent interaction with pedestrians and cyclists. In the future this could include sites such as airports, parks, retirement villages, university campuses and hospitals.

Alongside environmental impact, social equity is also an important policy consideration. Despite this importance some argue that due attention to environmental and social implications within the AV discourse is largely missing (Martin, 2018). Others suggest that whilst SAVs hold great promise, any lack of an intentional focus on equity in their deployment may just increase (transport) inequality (Cohen and Sahar Shirazi, 2017). Central to the social promise of AVs is the deployment of collective, shared transport (Francks, 2016). Such an approach is seen to offer greater transport reach (Chen et al., 2016), and provide more equitable, and inclusive transport – particularly in cities. Those who currently suffer from mobility shortfalls, or even transport-related exclusion, will then be mobility enabled. For example, older and younger people without driving licences, and those with disabilities or poor health who would not be able to drive, would regain access to motorised means of transport (Harper et al., 2016). Specifically considering the case of older citizens, this is a group identified as likely to experience mobility deprivation, with many having unmet travel needs (Bradshaw et al., 2013). To the extent SAVs could make passenger mobility services more available to older citizens without either the ability to drive or car access, then they may generate both significant direct and indirect benefits.

There is a note of caution around these visions of future mobility equity, as delivering such benefits will require consideration of factors such as gender preferences and habits, technology skills and digital divides, and the cost of services. Such issues may be particularly important in low income communities, where the potential replacement of existing transit services by SAVs may encounter technological and financial barriers to their use (Cohen and Sahar Shirazi, 2017).

However, none of the SAV scenarios are likely to materialise unless users adopt positive attitudes towards the new mobility system (Axsen and Sovacool, 2019), which means not only trusting in high levels of automation, but also being willing to share SAVs, including riding with strangers. The present article addresses two limitations of research to date on the theme of SAVs: first, that the studies are hypothetical, rather than based on real experience, and second, that they employ theoretical contexts and methods that emphasise individual attitudes and beliefs, and therefore underplay the social context, which is important both because individual perceptions are influenced by the social milieu, and because, when prompted either by the methodological or real-world context, individuals may place greater emphasis on social costs and benefits, and somewhat less weight on personal priorities.

The social context to individual attitudes and behaviour is important to transport policy in a number of ways, for example, mode-choice is important for an individual's self-presentation (Steg, 2004), social norms influence an individual's ratings of behavioural choices according to expectations about self and society (Cialdini et al., 1991), and individuals can display pro-sociality in their decisions whether to support transport innovations and policies, based on the expected consequences for close kin or others more generally (Nikitas et al., 2018). Despite the importance of the social dimension (Wei et al., 2013; Anderson et al., 2014), there have been few published studies relevant for road transport automation policy which consider the broader (social) context to acceptance, or apply research methods which would enable social considerations that might influence acceptability to emerge. One exception here is the focus group study undertaken by Harrow et al. (2018) focus group study, which provides an agenda for empirical research on future urban management in the context of AVs, and vehicle design, but does not seek to conceptualise the social facet of acceptability.

The present paper therefore makes three contributions: first, it reports on the value of the application of a co-design workshop methodology to the understanding of the acceptability of a future LSAVS; second, it develops a conceptualisation of social acceptability drawing on that method; third, it presents the application of that framework in the analysis of qualitative experiential data collected during two real-world demonstrations of SAVs in different application niches, one in Bristol, and one in London, UK.

2 Understanding SAV acceptance and the role of participatory design

Public or 'user' acceptance is a key factor for a successful implementation of SAV services; potentially a bigger barrier than the novelty of the technology to the adoption of AVs (Zhang et al., 2019). The literature provides different definitions of 'acceptance'. Najm et al. (2006) define 'acceptance' in the current context as "the precondition that will permit new automotive technologies to achieve their forecasted benefit levels". However, according to Xu et al. (2018) the psychological influences on public acceptance are not fully understood. In the past a series of theoretical models have been defined, primarily based on theories related to psychology and sociology, employed to explain technology acceptance and use (Seuwou et al., 2017). For example, the Technology Acceptance Model (TAM) (Davis, 1989) explains how users accept and use a technology and is itself derived from the Theory of Planned Behaviour (TPB) (Ajzen, 1991) which is a cognitive psychological model of individual behavioural intention and action. Based on these models, researchers have also identified safety (Xu et al., 2018) usefulness, self-efficacy, risk, and psychological ownership (Lee et al., 2019) as having a significant impact on willingness to use AVs. Trust in new technologies (Choi and Ji. 2015), comfort (Paddeu et al., 2020), privacy, and time sensitivity (Lavieri and Bhat, 2019) are also relevant factors influencing individual willingness to use SAV. Acheampong and Cugurullo (2019) also found positive relationships between environmental attitudes of participants and perceived benefits (e.g. reduced traffic congestion and environmental pollution) of SAVs.

TPB and TAM have been explored in AV and SAV surveys and some trials (Moták et al., 2017). However, TAM is not well suited to explaining complex decision-making processes nor forecasting actual behaviour (Bagozzi, 2007), and only able to explain 40% of variance in use (Wu et al., 2012). The consideration of moderating effects has resulted in the definition of more complex theories and models, such as the Unified Theory of Acceptance and Use of Technology (see Venkatesh et al., 2003. Venkatesh et al., 2012). These adopt complex assumptions concerning moderating effects, but lack theoretical argumentation (Bagozzi, 2007). More recently, new models to understand acceptance and adoption of AVs have been proposed by Hewitt et al. (2019) and Nordhoff et al. (2019). The former developed the Autonomous Vehicle Acceptance Model (AVAM), and the latter, proposed the Model of Automated Vehicle Acceptance (MAVA), based on personal exposure to AVs and systematic evaluation, and individual differences (e.g. socio-demographics, personality and travel behaviour).

Many of the above-mentioned studies are based on quantitative research, with a lack of qualitative research to understand technology acceptance and adoption. Nordhoff et al. (2018) is one exception, with these authors examining perceptions of people who had physically experienced a ride in a SAV. Prior to this, most studies relevant for SAV adoption had been based on online surveys based on hypothetical scenarios which asked people to imagine the future, indicating their attitudes and expected behavioural responses towards 'automated driving'. Vogelsang et al. (2013) suggest that the use of qualitative research is a key strategy to theorise acceptance that can be subsequently tested quantitatively. Participants in most published studies have rarely had experience with AVs, creating a limitation on the validity of the results if participants are unable to visualise a realistic experience (Xu et al., 2018; Nordhoff et al., 2019). One exception to this is the study by Axsen and Sovacool (2019) which explored understandings and expectations about LSAVS with participants who had either experienced a ride in a SAV, or had been in close proximity with one whilst undertaking their daily business, walking/cycling for leisure or utility reasons, or socialising in or enjoying public space.

Studies to date have mainly considered specific characteristics of individuals rather than groups, and aim at finding specific individual factors that can influence people's acceptance and adoption of SAVs. This highlights a lack of research towards what characteristics a SAV service should have and under what conditions it should operate. Users' expectations and preferences here are key factors for the evaluation of the actual potential impact of SAVs (Axsen and Sovacool, 2019). Thus, systemic evaluation needs to be informed by citizen perspectives alongside industry and policymakers' views. It is important to consider what value(s) potential users place on new (disruptive) mobility services (Bongaerts, Kwiatkowski & König T., 2017), and as a consequence how they would like services based on such technologies to be designed and deployed, as this too will have a bearing on their likely use. One way of achieving these insights is to use techniques of participatory design, or 'co-design'.

Such an approach can produce a wide range of perspectives, and generate innovative solutions that reflect well the self-identified needs of potential users (Cornwall, 2008). Co-design also allows those people who will be affected by decisions about technology adoption to have a substantive say in the outcome (Ehn, 1993). Importantly, a key benefit of a co-design approach is that responses (values) can be elicited both on an individual and at a collective level (Van Mechelen et al., 2017). The co-design approach has benefits not just for those designing a service, but also for future service users – not least because the outputs from the process incorporate those collective views. The broader benefits were collated by Steen et al. (2011); see Fig. 1 below.

Benefits	For service design	For users of the service	For the service provider
Improving idea generation	More effective idea generation & better ideas Knowledge of user needs		Focus on user needs Improved creativity, better cooperation.
Improving the service	Better service definition. More successful innovations	Better fit to user needs Higher quality service.	
Improving project management	Better decision making Reduced development time, lower costs, & continuous improvement		
Improving longer term effects		Higher customer satisfaction, more customer loyalty. Better informed users	More successful and effective innovation. Better relations with customers. Good Public Relations.

Figure 1. Benefits of co-design in service design (after Steen et al., 2011).

Through the co-design process, people are individually encouraged to think about their own values and trade-offs, whilst on a collective level personal values must be negotiated with other participants (implicitly or explicitly) (ibid). The presence of others can be expected to cue consideration of the needs of others, which is less likely to occur through the application of individualistic data collection methodologies unless very carefully designed in. Amongst multi-participant methods, co-design approaches can be more effective at idea generation than methods such as focus groups, perhaps in part because participants are focused on specific instances of use rather than more general discussions of user needs (Witell et al., 2011). The process can bring together input from people with many different perspectives, and the transport sector is seen to be 'remarkably open to some elements of co-design (Bradwell and Marr, 2008), although this notwithstanding, it remains a sector in which organisational cultures' are more likely to favour top-down rather than more collaborative design practices. Co-design is also seen to have benefits within the sustainable travel context, because it takes a more holistic perspective on issues and solutions (Mitchell et al., 2016). The citizen perspective, though, is best included when the individuals involved have a clear understanding of the service being offered; a point which was salient to the present authors in designing methods to investigate SAV social acceptance.

3 Overview of methodology

The paper draws upon two research projects. From the first of these, it reports on a co-design process for LSAVS and the deployment of a prototype demonstration service. From the second project, underway concurrently, it analyses data from a further prototype LSAVS demonstration. Details of the individual research activities are documented below. In the first step, a co-design workshop was undertaken with members of the public. This provided a user-centred perspective on LSAVSs, their design and operation, potential users and deployments. From the findings a conceptual model was proposed (Fig. 5, considered further below) which was then applied in Step 2. In this second stage citizen-participants in two LSAVS use-cases had the opportunity to ride in an autonomous vehicle in a real environment. These were a retirement development and a large public park containing several sports and leisure destinations. In these environments, as well as experiencing a ride in the vehicle, participants completed short questionnaires about the experiences and perceptions, or engaged in short interviews. Results from the interviews were organised in two datasets and were subject to coordinated thematic analysis. Table 1 summarises the research activities delivered across the two projects, and the number of people who took part in each activity.

Table 1. Summary of the research activities delivered across the projects and number of participants involved.

Step	Activity	Location	Date	Summary of method	N. participants	Proj
1	Co-design workshop	Bristol	March 2018	Wide range of activities related to design and use of LSAVS	60	Capr (Innc UK)
2	Trial 1 (T1)	St Monica's Trust, retirement village (Bristol)	May 2019	Short interview post ride in an local shared autonomous vehicle (LSAV)	23	Flour (Innc UK)
2	Trial 2 (T2)	Queen Elizabeth Olympic Park (London)	September 2019	Post-ride questionnaire (riders) and face-to-face interviews (others in the park)	56	Capr (Innc UK)

Drawing on these activities and operationalising the objectives at the end of Section 1, the remainder of the paper examines the following questions:

• What would an acceptable LSAVS look like? What are the key components of social • acceptability in this context?

• Did the participative-design process provide a mechanism to better understand the broader constraints of the social acceptability of SAV services?

• What policy implications for SAV services emerge from this analysis?

3.1 Step 1 – (L)SAVS co-design workshop

This event brought together members of the public with subject experts and research consortium members from industry and academia. A range of recruitment approaches were used for the co-design event, including targeted advertising on social media. During the first part of the event (induction) participants were informed about the activities they were going to engage with during the day and were shown videos and pictures of LSAVs. In the second part of the event, they were split into groups of six people and were invited to join a table to carry out a task that was specific to codesign a particular aspect of an LSAVS. The groups rotated across all the tables so that all participants took part in all activities. Tasks during the day ranged from identifying suitable locations for LSAVSs and the nature of the service network people would want to use, through to the design of vehicle cabin layouts. The third part of the event was a team-based competition, with a goal of designing a full LSAVS system – where it would operate, how it would operate, who would use it and specification of the service characteristics. Written, audio and video data were collected throughout the event for analysis. These were then sifted and collated before being analysed thematically by research project partners from industry and academia. The results are discussed in Section 4.

3.1.1 Sample characteristics

The sample was two-thirds male and one-third female. Half of the sample were aged under 34 and the other half aged 35–75.

3.2 Step 2 - LSAVS trials

Several AV and SAV research and development consortium projects have been conducted in the UK in recent years, generally with partners from industry, academic, and public authorities, and with grant-funding contributions from state actors. The authors have been involved in a social research capacity in some of these consortium projects, offering a rare opportunity to observe and collect research data. Short descriptions of the two projects and trials contributing to the present paper follow.

3.2.1 Retirement complex trial (trial 1)

Project 2 (Table 1) set out to explore the role of AVs for older people. It ran a series of trials involving older people in both simulator and live vehicle activities. Around one hundred people aged over fifty took part in trials held on and around a university campus, the oldest participant aged ninety. A final trial, held in May 2019 involved two days of live running in the grounds of a large retirement complex, or 'village' as they are often termed. The village site is extensive, with residential accommodation, social and leisure facilities, and on-site catering, laundry and other support services. It sits within its own grounds. The village offers residential accommodation, care facilities, and social activities. The distances (and topology) between some of locations within the village can present mobility challenges for some residents, and the site operator provides a minibus to support some of these needs (as well as transport to local shops etc.). Most residents buy an apartment to live in when they move into the village.

The trial used a four-seat fully autonomous vehicle (Fig. 2), which has two-passenger seats facing forward, and two facing backwards. For the trial, the vehicle was travelling at up to 5mph/8kmh on pedestrian routes within a closed, private site. Two or three participants were able to travel with the obligatory safety driver 1 in the vehicle at any one time

Figure 2. Flourish Local Shared Autonomous Vehicle (LSAV). Photo credit:

In this specific trial, the authors investigated the potential of an LSAV through the perspective of older people living in the retirement village, who had experienced a ride. Short interviews were conducted opportunistically with riders after their journey (N = 23). These were recorded and later transcribed. Interviews lasted up to 20 min. Participants were asked to reflect on their future mobility (and mobility needs), and to consider the potential uses and benefits of LSAVS.

The sample was aged 60 and over, with several in their 90s. Nineteen of the twenty-three interviewees were female. Most were still car drivers (or had access to a household car through a spouse who drove), although many were self-regulating the types of journey they made, and when they would drive (e.g. often not after dark). Walking aids and mobility scooters were commonplace amongst residents.

3.2.2 Large public park trial (trial 2)

The second opportunity to explore LSAV took place at the Queen Elizabeth Olympic Park in London during September 2019. The project explored potential commercial 'use cases' for LSAVS. The fully autonomous vehicle (Fig. 3) allowed two passengers to travel seated facing forwards and another two facing backwards (Fig. 4). During the trial, the vehicle was travelling at up to 5mph/8kmh on pedestrian routes in the park.

In this trial, the potential impacts of LSAVSs were investigated through the perspectives of people who experienced a ride in the LSAV as well as 'interactors': those who were walking or cycling in the park at the time the LSAV was circulating. As in the case of Trial 1 (T1), up to three members of the public could travel (with a safety steward) at any one time. Information about the experiences of riders was collected through a questionnaire, whereas the perceptions of the interactors were explored through face-to-face interviews. Both data collection instruments were designed considering the main factors identified through literature review and the co-design workshop delivered in Step 1. Both riders and interactors were asked questions about safety, and the operation of and interactions with the LSAV in a public space. Riders were also quizzed on experiential factors (speed, trust, comfort), and the kinds of location and circumstance in which they could foresee themselves using LSAVSs. Their views on willingness to share with unfamiliar others were also captured. Interactors were questioned further about operating regimes and appropriate policies and approaches for managing LSAVs in the shared public domain.

Figure 3. Capri Local Shared Autonomous Vehicle (LSAV) - Photo credit: Capri Project.

Figure 4. Cutaway of LSAV seating arrangement. Photo credit: Westfield Technology Group.

The trial at the park in London was advertised to those living and working around the park, although most participants were recruited from passers-by in the park at the time of the trial. Thirty-three people took a ride (typically 10 15 min) and completed a questionnaire, and a further twenty-three undertook an interview after being passed–by the LSAV. These interviews lasted between 15- and 20-min. Interviews were recorded and later transcribed. More males than females took part in the research, in part reflecting broader demographics in the park. Participants ranged in age from 18 to someone in their eighties. Distribution was spread across all age groups, with a slight bias to the 40–49 bracket. Most people normally walked in the park, although a significant minority were cyclists.

3.2.3 Ethics

All research activities described here were undertaken under appropriate university ethics committee approvals. No one under the age of eighteen was knowingly involved in the research data collection. All data collection was anonymous, and participants were advised they could withdraw at any point.

4 Research findings

4.1 Step 1 – Co-design workshop findings

The co-design event set out to review existing notions of what LSAVSs might be like, and to encourage the exploration of new ideas. The overall vision that emerged addressed a wide range of themes, with much interest in the technology and detail about operation of services. Alongside these topics, there were clear interests and concerns identified in the social domain: social equity, environmental benefits of societal significance, security and safety amongst the wider community of space users, and accessibility to mobility. Results relating to these themes were used to develop a model of social acceptability for LSAVSs (Fig. 5). The remainder of the current section is structured around these themes, and the model also underpins the analysis of the data from the real-world demonstrations considered in Subsection 4.2.

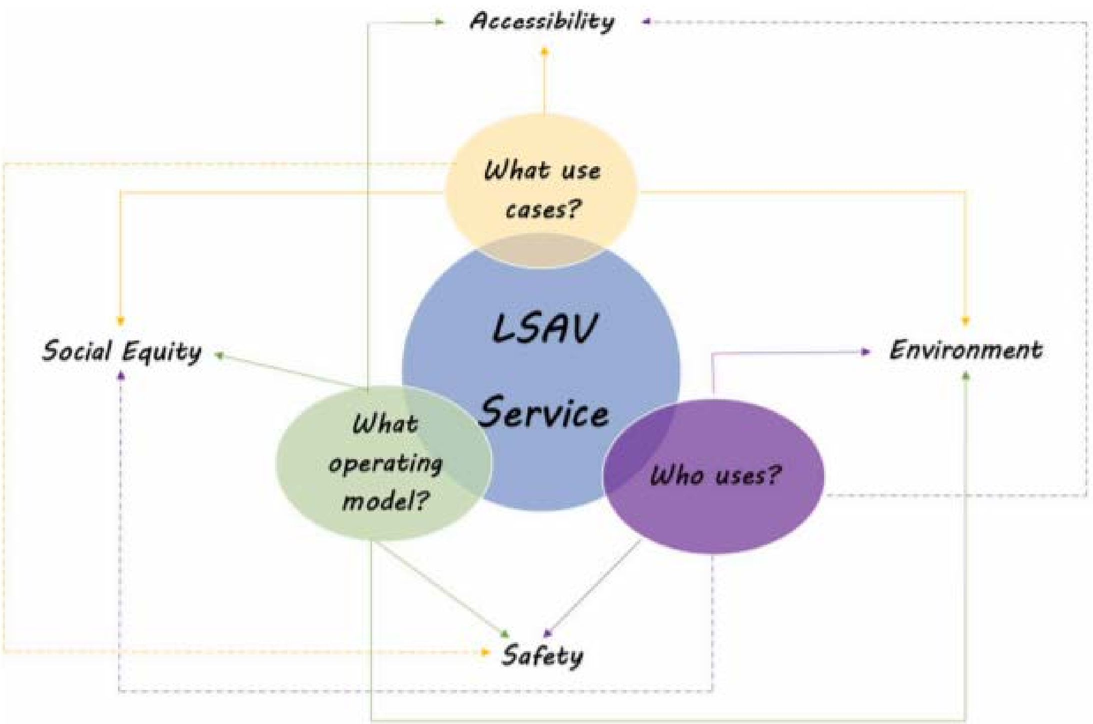

Figure 5. Social acceptability framework for LSAVS design.

4.1.1 Social equity

Social equity was an important issue for workshop participants, with LSAVSs seen to provide mobility for those who experience shortfalls in mobility, or lack of access to transport currently; circumstances identified as arising from patterns of provision of services, their cost, or social and cultural factors. To achieve social equity benefits, services would though need to be secure from crime and antisocial behaviour, safe to use as a transport service, and affordable. These attributes would be particularly important for vulnerable traveller groups.

4.1.2 Environment

Environmental implications of the use of LSAVSs emerged as a second key element in the vision. Participants thought that LSAVSs would offer the opportunity for a more sustainable future enabled through technology, for example using electric vehicles. LSAVSs would operate on-demand to service passengers when and where needed. With LSAVs operating as shared vehicles, there would be more effective use of space with reduced need for parking, so helping to 'free' cities from cars. Participants were not, though, able to judge what specific impacts LSAVSs might have on the environment and what the importance of those impacts might be, although they expected the LSAV to drive itself more efficiently than a human driver would, so congestion would be reduced, and they also expected vehicles to be electrically powered, with positive implications for air quality and climate change emissions.

4.1.3 Safety

The third key message from participants was in respect of safety and security, and the need for trust in AVs. The new technology needed to be proven to be safe; robust against hacking, for example. It must also be safe for other road users and pedestrians. Levels of safety proposed by the workshop were high, and much higher than currently expected of most modes of road transport (more akin to aviation and rail travel). Security from potential threats due to illegal or antisocial behaviour by others was also important, with explicit monitoring in the vehicle expected and wanted. Participants expected LSAVSs to follow a DRS model of sharing, albeit there were some concerns around vulnerable users and vehicle monitoring for safety. The possibility of women-only vehicles was raised, or extensive monitoring through mechanisms such as CCTV or live links to control centres. The defence of personal space within vehicles also emerged as important, with calls for LSAVs to be configured in such a way as to give clear indications about personal space allocations, so avoiding unwanted encroachment by others into the personal domain. Most controversial was the suggestion that users might have the ability to choose co-riders or see information about those already travelling in an LSAV, and potentially having the power to veto individuals seen as undesirable from joining the ride. The potentially socially-regressive nature of such powers was also recognised and objected to. However, building on the social distance' idea in a more progressive way, one group in the service design challenge during the co-design event focussed on 'event-driven' transport as a relatively deliverable niche; travel parties journeying to the same event might be relatively willing to share a shuttle due to the commonality of purpose and perceived sociocultural proximity.

4.1.4 Accessibility

The final key theme emerging from the co-design event addressed accessibility. LSAVs would need to be accessible for those with physical disabilities, and interfaces useable for those less able, or with sight or hearing issues. With such capabilities they could provide independence for groups who may not have that now. More broadly, the use of LSAVSs to deliver local mobility offered opportunities to plan new developments around automated mobility services, producing more holistic and sustainable solutions. In the longer term, LSAVS were foreseen in all new developments and should become part of the planning process. This was seen to potentially facilitate lower levels of car access across a range of future developments, particularly if supported by regulation or legislation.

Alongside these four elements of system design, Fig. 5 also identifies conceptual operational characteristics of LSAVSs, which participants were also tasked with codesigning. Discussions focused on who would likely to be using LSAVSs, what they would be used for, and how such services would be delivered (and by whom). How these questions are answered in reality will have a significant impact on the four elements of the community vision expressed in the co-design workshop. For example, single as opposed to shared use, and community ownership as opposed to personal. Step 2 sought to inform answers to some of these questions in the context of actual exposure to LSAVs.

4.2 Step 2. LSAV use cases examined through real-world demonstrations

In both trials, the data collection covered the research themes in the Social Acceptability Framework (Fig. 5) and other topics important for the specific research projects (the user interface and interactions with other users of the space respectively). T1 data collection used a more open-ended, participant-centred research instrument, whilst in T2 the approach combined more structured questions with interviews, due to the more limited contact time it was possible to have with opportunistic recruitment in T2 compared with participation programmed in advance in T1.

Trial participants (a self-selected group at T1) were generally positive about the idea of LSAVSs operating in the retirement village and for those in T2, to see them in the park.

“It was very nice, and I wouldn't mind sharing the space with AVs. I hope to see more in the future … " (T2, middle-age male)

In terms of wider LSAV applications, riders in T2 also foresaw the application of LSAVSs at airports, for shopping, at a hospital or within a university campus, or to commute to work or school/university. Few respondents said they would not use one at all.

Six participants at T1 had concerns about LSAV-style vehicles taking to the road. Two were particularly concerned about a mixed environment, with non-autonomous vehicles still in use. They would feel more vulnerable in that context, and subject to other people's behaviour(s).

Participants from both trials could see how they might use fully- autonomous vehicles in the respective trial locations. Three T1 participants made comments about using the vehicles to traverse the retirement complex and another noted it would allow them to reach an adjacent bus stop. One older female saw the service being constrained to the village positively:

“… it also made a difference being in a closed environment. I knew where I was going, and I knew where I would get back to …” (T1 older female)

Two participants in T2 added journey context-based justifications: use in case of poor weather or if carrying heavy objects.

The remainder of this subsection now considers the four themes from the Social Acceptability Framework.

4.2.1 Social equity

Fifteen participants interviewed in T2 suggested LSAVSs might be used to support the mobility of older people and people with mobility issues. There were though concerns from several participants about the cost of services in the retirement village (T1), although two expected that any LSAVS would be provided for residents as part of an inclusive package – similar to the minibus available currently. One interviewed participant in T2 suggested national authorities (e.g. the UK Government) should pay for use of LSAVSs by the less able.

“I think it depends on who it is carrying. The Government should pay for older people or disabled. But if it is just a family who wants to jump on it, they should pay then.” (T2, older female).

Ten interviewed participants in T2 thought that LSAVSs should be primarily for those with reduced physical ability. Those that were able to walk or independently move should pay (perhaps through a subscription) to use an LSAVS. There were also concerns around the potentially negative impacts of LSAVSs replacing cycling or walking (T2), with participants keen that LSAVSs were: “not for people who are not disabled or can walk” (T2, younger male), especially in a context like a park. LSAVSs were seen to be a good alternative to existing mobility services for the less able in locations such as the park.

4.2.2 Environment

When quizzed, participants would assume LSAVs would be powered electrically, but two participants interviewed in the park (T2) had concerns about the availability of charging infrastructure. One resident in T1 suggested that the quietness of electric vehicles would be a safety risk amongst older people.

Two participants at the retirement village expected LSAVs would drive themselves more efficiently, with positive impacts on congestion. Similarly, others thought people would own and use fewer cars, as LSAVSs would increase mobility options, making private car ownership and use less attractive, again reducing congestion. There was little consideration of the wider environmental impacts of LSAVs at the retirement village. Similarly in T2, the interviewed participants were, with two exceptions, not willing or able to judge if LSAVSs would reduce the number of vehicles on the road, as well as the related congestion and polluting emissions.

4.2.3 Safety

Thirteen participants in T1 made explicit comments about safety: most felt safe travelling in the prototype LSAV, because of the slow speed of operation and the evident safety marshalling. Three participants were concerned about safety should they be travelling at higher speeds, and one about the robustness of the vehicle used in the trials. Another response expressed the view that vehicles should be tested and deemed safe before deployment in these environments.

Marshalling was lower-profile in T2. Thirty riders trusted the LSAV in terms of how it responded to events. Nine riders expressed concern in respect of safety for other users of the space (pedestrians and cyclists for example). Again, the few concerns may have reflected the low speed of operation in the trials.

There were concerns about interactions between LSAVs and human drivers in mixed environments (T2), as five interviewed participants thought that human beings might find it difficult to make decisions when driving in the same space as an LSAV.

One T1 participant in the retirement village was concerned about her fellow residents’ vulnerability mixing with an LSAV:

“I would have concerns about the people in the retirement village who use rollators (walking frames), wheelchairs, scooter users … and how pods will interact with them. It could be very dangerous” (T1, older-old female).

However, positive attributes pertaining to LSAV operation were also identified:

"… I like the idea of something that can't go too fast, something that is electric, and something that can stop if there are people around" (T2, middle-age male) .

One T2 cyclist interactor participant said he would prefer having LSAVs than human driven cars as he perceived

LSAVs being safer, a view echoed by another participant:

"I would feel safer with more autonomous vehicles and less human drivers" (T2, older female) .

Seven respondents in the park imagined LSAVs would circulate on a separated lane, "like a cycle path", not interacting with general traffic. Interestingly two younger cyclists at the park (T2) preferred not to share space with motorised vehicles at all, including LSAVs. They were though happy for them to operate in other environments, such as an airport:

"It is a big machine and I wouldn't like to see it in the park. I would prefer to see people (e.g. pedestrians, cyclists, e-scooter users" (T2, younger male).

Considering what would happen if there were to be an operating incident, two older residents in T1 raised the issue of a lack of help in an emergency and were not persuaded that talking to a remote assistance steward via a communication system in the LSAV would be sufficient for reassurance or practical purposes. However, there were no calls in either trial for a steward to be travelling in the LSAV for safety reasons once it had been proven for regular, fully-automated service.

An important subtheme which emerged from the real-world trial data related to safety and security when vehicle-sharing. Seven T1 participants expressed views on sharing an LSAV. Five were happy to do so, although two with a proviso about it being a short-duration journey. Only one was negative about the idea of sharing, particularly sharing with strangers. Similarly, T2 participants expected that they might share with strangers, with only two riders expressing slight discontent. Twelve riders would also be willing to take a slightly longer route to pick someone else up if it could result in a lower fare.

4.2.4 Accessibility

Fifteen of the participants in T1 were car users, although several of them used public transport or the village minibus to travel for shopping or into the city centre (where parking issues were a deterrent to driving). Nine participants noted some degree of self-regulation of their travel outside the village. Four residents of the village experienced difficulty with journeys within the village, due to health constraints combined with distances between facilities. These difficulties impacted on their social and communal activity, which an LSAVS might address.

“I am sure they will help a lot, especially for people with mobility issues and older people, who can't walk for longer distances. Especially in locations like this … to enjoy a ride in the park” (T2, Middle-age male).”

Two T1 participants thought that LSAVs would help them with mobility around the village, and two more would use them for social activity outside the complex. For some this would aid their independence:

“I do like my independence, and this could allow me to travel when I want to” (T1, Older female).

As in T1, participants in T2 thought LSAVs would indeed become a mobility option integrated within the broader transport system in the future, despite the “high uncertainty in terms of technology development”, “regulations” and “safety issues”. One participant argued that LSAVSs would be more efficient than human-driven cars, and three interviewed participants suggested an LSAV would circulate in the park similarly to a bus, following a specific route with predetermined stops. One participant imagined the future transport system will allow space only for buses, LSAVs, cyclists and pedestrians, with complete elimination of human-driven cars.

4.3 Synthesis of codesign workshop and LSAVS demonstration findings

The key themes emerging from the co-design event and from qualitative research in the two LSAV trials provide insights into understanding their social acceptability, and how to optimise social value from, and therefore support for, LSAVS deployed in these discrete types of environment.

It is apparent that when thinking about what is seen to be an entirely new form of transport that some citizens approach the opportunity in an optimistic, even utopian, way. They seek to use the expected ‘transport revolution’ to address a wide range of perceived shortcomings in existing transport services, and indeed inefficiencies, injustices and inequalities beyond the transport and mobility sector: in wider society. Thus, concerns over isolation, access to services and facilities, and transport as a form of ‘commons’ emerged in the co-design discussions as expectations of a new service, even if existing services are, de facto, accepted despite not addressing all those needs.

Not surprisingly, given that the salience of both climate change and poor air quality as policy problems grew markedly during the time in which the research was conducted, pro-environmental attitudes were also to the fore. LSAVS were perceived to be amongst the class of solutions fit for a society increasingly responding to the climate emergency and introducing restrictions on vehicles emitting noxious pollution.

The conceptual model introduced above (Fig. 5) reflects a community-oriented basis for system design, intended to maximise broad social acceptance. Given the potential tensions around vehicle sharing, and that these varied with trial context, those proposing LSAVSs will need to consider carefully the trade-off between individual user-acceptance, perhaps by a minority committed to exclusive use, and broader social acceptance incorporating broader social equity concerns about affordability and exclusion. Such tensions may be particularly sharp from a commercial perspective, where specific target users may be envisaged, and an 'omnibus' service may not be seen as the most profitable or deliverable option. Such decisions will interact with choices about the routes or locales to be served and the extent of public-sector participation, whether through service or rider subsidy, or perhaps a franchise with public service obligations.

5 Discussion

5.1 Key components of SAV social acceptability

The findings of the paper in respect of our first research question concerning the key attributes of the social acceptability of SAVs emphasised four dimensions. In terms of accessibility, it was indicated that a 'prosocial' vision of future LSAVS operation is associated with last/first-mile journey segments integrated with other modes and short-range local journeys, the latter with a special focus on people with mobility issues, including older people. The low speeds of the LSAVs in the trials rendered them relatively suitable for integration in already-busy environments, but also made them a less attractive option for those people who can use active travel modes (e.g. walking/cycling), a 'deterrent effect' also noted by Nordhoff et al. (2019). Whilst this deterrent effect might limit the attractiveness to a commercial operator, the low speeds would in fact support the public health policy objective, for those citizens who can, to be physically active.

From the perspective of the environment, some participants in this study suggested LSAVSs should adopt a 'shared-ownership' model, similar to car-share schemes, which could significantly reduce private car ownership and parking needs and could have a strong impact on spatial planning and road network management. Sharing remains a key issue in terms of the potential environmental impacts of LSAVSs, as if a shared LSAV is expected to reduce congestion, pollution, and the number of collisions, a non-shared use would potentially produce results in the opposite direction. For this reason, policymakers should encourage and support shared mobility with current technologies (e.g. car sharing, carpooling) in the present, in order to prepare people to share automated technologies in the future, when the consequences of individual mobility are predicted to be much greater (Wadud et al., 2016).

Safety had already been recognised as an important factor for social acceptance (Hussein et al., 2016; Koopman and Wagner, 2017). There was an expectation amongst our respondents that LSAVs would be intrinsically safer than human-driven vehicles, as they would be driven by a control system that would make fewer errors (Fagnant and Kockelman, 2015). However, our participants were not supportive of LSAVs operating in general traffic conditions, interacting with other modes including motor vehicles, cyclists, and pedestrians, because they perceived the system would be too complicated, with a negative impact on safety. This was also highlighted by Campbell et al. (2010), who argued a mixed traffic environment could be too challenging to allow LSAVs to drive themselves safely in every situation. Indeed, some participants specifically thought that human drivers might be more efficient in more complex traffic environments, in line with the belief that human drivers can recognise human beings and other objects in the roadway more easily than (L)SAVs (Dalal and Triggs, 2005, Economist Technology Quarterly, 2012; Farhadi et al., 2009). Given that LSAVs are likely to operate at slower speeds than general motor traffic, the speed differential and possible aggressive responses from motorists feeling impeded by them could indeed cause a rise in collisions. At the same time, however, the provision of an entirely segregated set of reserved lanes for a new automated transport system would be extremely challenging, and has been hard to achieve even for modes such as human-driven public transport buses, for which the reservations do not necessarily have to be continuous.

In respect of social equity, participants thought LSAVS could bring mobility and inclusion benefits for older people and the less able. They might address issues such as isolation, and provide greater independence for these groups. The cost of these new services did emerge as an issue for the retirement village participants, but the general expectation was one of services being provided free of charge by the operator of the village. Participants in both trials thought services should be free of charge for certain groups of less able users and the Government should cover costs via a 'concessionary travel' scheme in order to foster social equity. This could have significant implications in respect of funding, and user expectations. Older groups would need training in how to use vehicles, and issues of digital literacy become pertinent here, particularly among the older old who are less likely to be familiar users of digital devices. Although the availability of LSAVS could be seen to increase the demand for mobility, and thus increase the numbers of vehicles and trips (Krueger et al., 2016, Fagnant and Kockelman, 2018), this demand will, to begin with at least, be constrained to niche locations.

5.2 Value of participative co-design process

The second research question considered whether adopting a participative-design process provided a mechanism to better understand social acceptability issues in respect of SAV services. The findings, generated from interactions between over sixty people working together to provide solutions and designs for LSAVSs in particular, suggest the process did. The event provided participants with the opportunity to develop and inform their viewpoints across the day as they experienced different voices in the discussion, and they were able to take in knowledge from experts attending the event as well. This generated better-informed responses. In particular it provided a service design that matched user needs, with those user needs reflecting parameters of social acceptability. The testing of these findings from the co-design workshop within two LSAV live trials provided the opportunity to then verify the key themes and views identified. Results from data collected within the two trials with the LSAVs (T1, T2) exhibited high consistency.

5.3 Policy implications for future SAV services

The third question considered implications for policy. A number of trends suggest that the need for LSAVS could increase in the future. First, it is likely that restrictions on internal combustion engine vehicle use will grow, particularly in urban areas, and LSAVSs could make such restrictions practically possible and politically acceptable, by providing an alternative to those for whom walking the final leg is not an option, perhaps due to heavy luggage or being accompanied by young children.

Second, increasing numbers of citizens are not choosing to become car drivers, or are not able to maintain car driver status, because they delay learning to drive, never learn to drive (Chatterjee et al., 2018), or, in the context of an ageing population, give up driving for health or ability reasons. Such citizens can be expected to use collective solutions more, and LSAVSs can potentially offer 'last mile' connections to public transport bus and rail services, therefore increasing the overall viability of the collective transport network.

Third, and partly related to the last point, whether they are able to drive themselves or not, the ageing population is associated with a rising number of people with locomotive restrictions and which require a door-to-door or near-to-door vehicular mobility service, as well as a rise in the 'quasi-able', who can walk, but not long distances, and only at slow speed, possibly with discomfort. In the present research, older citizens in particular identified benefits, although also specific concerns, around the usability of digital technologies to access both the service and remote assistance whilst on board. Nonetheless, LSAVSs might offer a way of achieving a level of accessibility for older travellers in particular in a way that is zero local emission, low visual impact, and using a controlled and managed driving style which is respectful of other users of public space. The alternative might see a rise in the private car population in environmentally sensitive areas, as an increasing number of access permits need to be issued on mobility-inclusion grounds.

The research undertaken with participants reported in this paper underlines that citizens recognise the above trends and that LSAVSs might be part of the policy responses. However, their positive, arguably optimistic, expectations about LSAVSs in the future as a socially-progressive, low environmental impact form of more effective mobility showed some contradictions. These contradictions existed both amongst an individual's views, as well as between individuals, the latter point underlining that it may be impossible to deliver each participants' vision of an LSAVS future. First, whilst LSAVSs are welcomed on the one hand for the benefits they would bring for those with mobility limitations for journeys of up to 2 km in campus environments, on the other hand, others did not wish to see a further mechanisation of travel in spaces seen as reserved for pedestrians, and sometimes cyclists. LSAVSs might indeed become a very convenient option for people who would be able to walk or cycle, and although some non-user participants were relaxed about sharing space, in some times and places, LSAVs might have a negative impact on the freedom of the active travel environment. This suggests the way LSAVs operate and the services they provide should be designed in a way that would not be appealing for those able to choose active travel options. Finding a policy solution that encourages mobility by some citizens but not others is likely to be challenging: it might need to operate according to a permit system or by making the services not 'too' attractive – the clue here for LSAVs is perhaps that the operating speed in the trial was found by many to be slow; not competing with the speed of cycle use might therefore be a policy objective, although it would likely not be popular with commercial operators. However, LSAVs offered as a contingently-attractive option might face a heightened challenge around matching supply and demand, as very significant spikes in demand could occur given the combination of particular events (e.g. concerts, sports events) and during poor weather.

Another important tension emerged around path negotiation in spaces shared with active travellers and micro-mobility users. People who participated in this study suggested LSAVs should circulate in separate space/lanes in order to work efficiently, to manage the fact that they would stop anytime an external user/obstacle would get close to the vehicle. This would reduce the operational efficiency of the LSAV and the overall system performance. However, the advantage of more complex autonomous technologies over simpler guided systems is substantially eroded if the vehicles are unable to take advantage of the flexibility that artificial intelligence' brings, because they are confined to segregated corridors. Policy makers and planners will'need to consider the design of spaces proposed for LSAVSs, with a view to establishing whether it is possible to provide an appropriate means of sharing space without dominating it, whilst also allowing LSAVs sufficient efficiency of operation to make the offer attractive and worthwhile.

Lastly, regarding the costs of providing LSAV systems and adapting public space, the participants were not particularly vocal, but where they did raise issues of funding, most expected public authorities or private agencies to pay. That may be plausible for a dedicated service within the confines of a private, commercial estate, such as an airport or retirement complex, but the wider range of potential applications and the related business models will need to be fully evaluated to establish where the value proposition lies and whether it is of commercial relevance or can be justified as a subsidised public service.

6 Conclusion

The implementation of an innovative solution (designed by experts) needs public acceptance to be successful in the long-term, and social acceptance becomes a key factor affecting the time between the introduction of a new concept and its actual implementation. In social psychology 'social influence' is a "change in an individual's thoughts, feelings, attitudes, or behaviours that results from interaction with another individual or a group (Ritzer and Ryan, 2010). Social influence is therefore an important factor for the intention to use an LSAVS by"an individual. Several authors have acknowledged the importance of social factors on technology acceptance and adoption (Vannoy and Palvia, 2010). However, the most high-profile technology acceptance theories, such as TAM, are mainly based on individual characteristics and do not include social constructs, which represents an important limitation (Niehaves et al., 2012; Taherdoost, 2018).

The present paper has demonstrated the relevance and value of a methodological approach oriented towards exploring people's perceptions and expectations towards LSAVSs in a social context and with a social acceptance perspective, and proposed an initial 'social acceptance framework' (Fig. 5) for understanding the key factors and trade-offs influencing social acceptance. The findings revealed citizens to have strong and positive aspirations for the deployment of AV technologies, in particular requiring that they:

- provide new accessibility solutions that will be available to all,
- reduce rather than increase the local and global environmental problems faced by society at large,
- address inequalities in safety and security whilst travelling, and
- offer solutions relevant for social inclusion policies, such as tackling isolation amongst older people.

Indeed, probably the greatest policy problem posed by LSAVSs (and perhaps AVs in general) will be managing the wave of expectations built up amongst engaged members of the public about the promised 'mobility revolution'. The findings reported in the present paper identified utopian beliefs that many of the seemingly intractable problems of a national multi-mode and multi-operator booking and payment system will be solved, simply because it would be 'unthinkable' to have a major investment in a new technology which then recreated the perceived failings of the existing systems. However, there is of course no tangible reason why such problems would easily be solved for a new LSAVS when they have not been, to date, in most states and in most cities, for transport systems based around humans driving.

Similarly, expectations regarding safety and security were that the system would be on a par with aviation or rail travel, despite the fact that, unlike those other modes, LSAVs would need to interact with other vehicles, road users, and street uses. That these expectations of inevitable and desirable progress were interspersed with sharp practical questions about how particular aspects of this vision could be fulfilled in technical terms underlined these fundamental contradictions. Above all, then, policymakers must look beyond the attractiveness to industrial policy of the new technologies, such as LSAVSs, and their own subjective optimisms, to engender an informed and challenging debate about the ways in which AV technologies are adopted in the transport sector, and indeed, whether society is really willing to make all the changes that are implicit in the visions considered above with a view to making AV adoption socially acceptable.

Declaration of competing interest

None.

CRediT authorship contribution statement

Daniela Paddeu: Conceptualization, Investigation, Methodology, Writing - original draft, Writing - review & editing. Ian Shergold: Conceptualization, Investigation, Methodology, Writing - original draft, Writing – review & editing. Graham Parkhurst: Conceptualization, Investigation, Methodology, Writing - original draft, Writing - review & editing.

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