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Understanding acceptance of autonomous vehicles in Japan, UK, and Germany

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ABSTRACT

This paper investigates the acceptance of Autonomous Vehicles (AVs) in Japan, the UK and Germany and speculates on the implications for policy and practice. Three on-line surveys of 3,000 members of the public in total, which were conducted in January 2017 (Japan), March 2018 (UK) and November/December 2018 (Germany) were analysed using Principal Component Analysis and then with an Ordered Logit Model. It finds that acceptance of AVs was higher amongst people with higher expectations of the benefits of AVs, those with less knowledge of AVs, and those with lower perceptions of risk. It also finds frequent drivers and car passengers to be more accepting, but that socio-economic factors were mostly insignificant. Finally, there were significant cultural differences between the levels of acceptance between Japan (broadly positive), the UK (broadly neutral) and Germany (broadly negative). These findings suggest that AV promoters should raise (or at least maintain) expectations of AVs among the public; engage with the public to reverse the negative perception of AVs; address AV-generated fears; not bother targeting people by socio-economic group; target frequent car drivers and passengers with information about what AVs could do for them; and target countries where AVs already enjoy a positive image.

1. Introduction

Several recent studies speculate that so-called 'driverless cars' or 'Autonomous Vehicles' (AVs) will inevitably replace the human-driven motorcar as the dominant mode of passenger transport on our roads (e.g. Gruel & Stanford, 2016; Lipson & Kurman, 2016) for two related reasons. First, AVs are expected to reduce road traffic accidents, increase values of travel time, reduce energy consumption and pollution, and increase mobility and accessibility for all (Fagnant & Kockelman, 2015). Second, these benefits have led to massive investment by many major vehicle manufacturers and technology

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companies (see, Chan, 2017) in AVs, with one estimate suggesting that the global AV market revenue would be \$US126.8 billion by 2027 (Infoholic Research, 2017).

In preparing for this AV paradigm, we need to understand the level of societal acceptability AVs will experience. Rogers (1962) found that acceptance and dissemination of innovative ideas and technologies into society has the same importance as research development and innovation activities. Interestingly, the path to societal acceptance is likely to be different in different countries around the world due to automobility cultural differences being strongly influenced by national cultural characteristics (Edensor, 2004).

Accordingly, the aim of this study is to investigate the acceptance of Autonomous Vehicles (AVs) and a dedicated questionnaire was used to gather data from Japan, the UK and Germany.

2. Literature review

The literature review explores some of the literature around acceptance as applied to AVs.

2.1 Autonomous vehicles and acceptance

Autonomous vehicles can be classified according to the degree over driver control of functions such as braking, steering, lane changing, and parking, into six levels ranging from Level 0 (no driving automation) to Level 5 (full driving automation; SAE International, 2021).

Acceptance by users and policy makers is a vital pre-condition for making use of an innovation such as an AV. In other words, a positive intentional attitude towards an innovation is required before it can be adopted. Adoption can be summarised as the behavioural level of someone taking action and actually using the innovation (Bagozzi & Lee, 1999). Quantifying acceptance as a single index however, has so far proved challenging – for examples see, A. Takahashi and Kamada (2016), Mukaidono (2009), T. Takahashi and Sato (2014), and Tanaka (1995). Therefore most studies consider a range of factors.

2.2 Attitudinal factors and AV acceptance

Economic attitudes: An internet-based survey poll of 347 citizens of Austin, Texas reported that respondents' average willingness to pay (WTP) for adding partial (Level 3) automation capabilities to their current vehicles were less than half than for fully autonomous vehicle functionality (equivalent to Level 5) (\$US3300 instead of \$US7253; Bansal et al, 2016). Slightly different results were reported in Daziano et al. (2017) which estimated that the average US household is willing to pay \$US3500 for partial automation and \$4900 for full automation. Kyriakidis et al. (2015) conducted an online questionnaire survey of 5,000 citizens among 109 countries and found that 22% of the respondents would not pay any extra money for a fully functional AV, whereas 5% indicated they would be willing to pay more than \$30,000. Souris et al. (2019), found that cost was one of the main factors affecting attitudes and choice of AV by Greek drivers.

Takahashi et al., (2016) considered how fully autonomous vehicles performed, based on how the user valued the loss of being able to own and/or drive their own car. Specifically, the value of a vehicle was divided into user value – user cost, and social value – social cost. They found that additional value would need to be generated to offset the value provided by the perceived 'pleasure of driving' if AVs are to be accepted.

Safety risk: Safety is related to risk insomuch that as safety improves then risk, the probability of negative occurrence caused by controllable and uncontrollable factors, is reduced. This is important in this case, because one key aspect affecting the acceptance of AVs by society is the fear that the roads will become more dangerous if AVs replace driver-controlled vehicles.

Mukaidono (2009) indicated that making something 100% safe is impossible. Instead, information about, and the handling of residual risk must be revealed as usage information. Moreover, tolerable risk varies by time and in different social situations. It is necessary to be aware that products always involve some level of risk and that consumers should be able to have sufficient self-awareness to perceive risk and be responsible enough to use products as safely as possible. Yet 'acceptable risk levels' are not always rationally judged. For instance, there are cases where the mass media focus on specific novel technologies and by doing so skew how they are perceived and addressed. One could therefore imagine that any accident involving an AV would be treated as a major issue, even if the overall evidence demonstrated that AVs were safer than other technologies. Meanwhile AVs were perceived as a 'somewhat low risk' mode of transport, and there was little opposition to the prospect of their use on public roads (Hulse et al., 2018). Interestingly, AVs were seen as being riskier than a human-driven car by car passengers, but safer by pedestrians.

Other attitudes: Suzuki (2016) explored several non-technical issues relating to the realisation of AVs, namely: (a) the relationship between AVs and the driver, (b) the relationship between AVs and other road users, and (c) fostering societal acceptance. For (a), it highlighted an ethical issue in that 'AVs may sacrifice safety to maintain driver compliance'. For (b), an important element was the loss of communication afforded by eye contact between AVs and other road users. For (c), it was acknowledged that robot taxis and car sharing are attracting attention in the United States as a business model, while in Europe development is progressing as a form of public mobility. A study of 421 French drivers reported that 68.1% of the sample were accepting of AVs, and that the best predictors of intention to use a fully AV were mainly attitudes towards automated driving, contextual acceptability (on highways, in traffic congestion and for automatic parking), an interest in impaired driving, and driving related sensations, e.g. thrill seeking (Payre et al., 2014). Haboucha et al. (2017) explored five relevant latent variables describing individuals' attitudes around technology interest, environmental concern, driving pleasure, public transit attitude, and pro-AV sentiments, and determined that 44% of respondents would still favour ordinary vehicles over AVs.

2.3 Individual factors and acceptance of AVs

In a survey of 721 Israelis and North Americans, Haboucha et al. (2017) found that early AV adopters will likely be young, students, better educated, and spend more time in vehicles. Hulse et al. (2018) found, from a survey of almost 1,000 people, that gender, age

and attitudes to risk-taking impacted on the perceived risks of different vehicle types and general attitudes towards AVs, such that men and younger adults were more accepting. A questionnaire survey of the general public in Japan by the National Police Agency (2016) found the differences in expectations, concerns and attitudes towards AV demonstration experiments depended on gender, age, and driving licence ownership, experience of traffic accidents, but not by region.

2.4 National (cultural) influences on AV acceptance

Culture can be defined as being 'the ideas, customs, and social behaviour of a particular people or society' (Oxford English Dictionary, 2020) and refers to often invisible characteristics around shared norms, values, and mutually reinforcing behaviours of a range of entities including organisations, geographic spaces, local communities and nation-states. The following section reports how the extant literature has explored the influence of national culture on attitudes and behaviour related to the potential adoption of AVs.

Steers et al. (2008) noted that little in the way of systematic research has been done to examine the extent to which national cultural differences influence the adoption of available emerging technologies. In terms of the influence of culture on the acceptance of AVs, a Europe-wide survey conducted in September 2019 revealed culture to be a major influence on people's willingness to use autonomous vehicles, with the proportion of those who said yes ranging from only 37% in France to 57% in Denmark (43% in Germany and 45% in the UK; European Commission, 2020), though with significant heterogeneity underlying these answers. Next, Potoglou et al. (2020) examined the predictors of consumer interest in and willingness to pay for both autonomous vehicles through a choice experiment in Germany, India, Japan, Sweden, UK and US and report significant heterogeneity both within and across the samples. Specifically, while in Europe travellers need to be compensated for automation, in Japan consumers are generally willing to pay for autonomous vehicles. Segments within countries most enthusiastic about AVs typically had a university degree, and self-identified as being pro-environmental and as being innovators. Haboucha et al. (2017) found that Israelis would be more willing to share AVs than North Americans. Sovacool and Griffiths (2020) noted how culture informs not only vehicle use, driving patterns and end-user behaviour, but also the programmers and modellers setting up systems that do not recognise pedestrians with darker skin colours or people riding bicycles for example.

Hofstede (2011) established six dimensions to measure the influence of national cultures, namely: Power Distance, Uncertainty Avoidance, Individualism/Collectivism, Masculinity/Femininity, Long/Short Term Orientation, and Indulgence/Restraint. At this point it is important to note that there are limitations. In particular, Venaik and Brewer (2013) for instance, point out that researchers should be cautious in using the Hofstede national culture dimension scores for analysis at the level of individuals and organisations. Nevertheless, it does remain a useful tool and has been widely applied by academics since its introduction.

In applying the Hofstede (2011) dimensions to AVs, Escandon-Barbosa et al. (2021) reported that in Vietnam, a country with a low degree of indulgence, the take up of AVs would likely be slower due to concerns over obsolescence and durability than in a high indulgence country such as Columbia where buying behaviours are more emotionally

governed. Gopinath and Narayanamurthy (2022) applied a Technological, Individual, & Security (TIS) model to conceptualise AV use which confirmed the influence of culture, as well as automation level, and ownership status as strong predictors of AV adoption. They also concluded that further work was needed to understand the impact of cultural impact in the multinational development of AVs, a position also supported by Leicht et al. (2018). Similarly, Kaye et al. (2020) found national culture to be significant in a study of AV adoption in Australia, France and Sweden. And Yun et al. (2021) compared Hofstede's indices against the public's concerns about AVs and their willingness to pay for AVs in China, India, Japan, the U.S., the U.K., and Australia, to predict outcomes for South Korea. They found that more individualised societies were less willing to pay for AVs; and more indulgent and less hierarchical societies were less willing to pay for and less concerned about AVs, but that levels of uncertainty avoidance were insignificant in terms of willingness to pay and level of concern about AVs. Thus they confirmed that cultural differences play an important role in the acceptance of autonomous vehicles, and the need for further study.

2.5 Research gap

From the literature reviewed, several studies have investigated the social perceptions of developers, engineers and the general public relating to AVs, though fewer studies were found that measured the extent to which attitudes towards risk and national cultural differences influence the adoption of AVs. This study aims to contribute to current knowledge by examining the acceptance of AVs by also addressing cultural particularities via country comparisons.

3. Materials & methods

3.1 Hypotheses of this research

Hypothesis 1: Acceptance of AVs depends on how individuals perceive risk, as suggested in Section 2.2.

Hypothesis 2: Acceptance of AVs varies by the circumstances of an individual (e.g. current travel behaviour, gender, age, driver licence, car ownership, and region), as suggested in Section 2.3.

Hypothesis 3: Acceptance of AVs depends on national culture, as suggested in Section 2.4.

3.2 Survey method

The study applied three online surveys to investigate the individual, attitudinal and cultural predictors of risk perception towards AVs and relates these factors to the level of acceptance for the technology by individuals in countries that are potentially major markets for AVs and so are important contexts in which to explore preferences for and

potential adoption of new technologies. Specifically, six distinct regions spread across three culturally diverse countries: Japan (Tokyo and Nagoya), the UK (London and the West Midlands) and Germany (Berlin and the Ruhrgebiet) were analysed to ascertain the influence both of national and sub-national cultural traits. Japan and the UK were selected to reflect the geographical location of the authors of the paper at the time. Subsequently, some similarities were observed in that both countries in terms of the size of population and economy and the importance of industrialisation (and car manufacturing in particular), and this led to the adoption of Germany as a country with matching characteristics as a third case for the study.

Fortuitously, at the national level country comparison scores measured using the Hofstede-Insights tool (see https://www.hofstede-insights.com/country-comparison/germany,japan,the-uk/) show some fascinating differences in how each society functions (see, Table 1).

Thus, from Table 1, Japanese culture is highly masculine, has a long-term orientation and craves certainty, and is more hierarchical than the UK and Germany, but much more collective. UK culture is more individualistic and indulgent and is more short-termist and comfortable with uncertainty than both Japan and Germany. Germany is similar to the UK in terms of power distance and masculinity, but similar to Japan as regards its long-term orientation and favour of restraint. At the sub-national level, Tokyo, Berlin and London are capital cities with high population densities, high levels of public transport use and relatively low levels of car ownership; whilst Nagoya, the Ruhrgebiet and the West Midlands are regarded as being industrialised heartlands, each with a long tradition of car manufacturing, and therefore assumed to be more 'car friendly'.

Three web-administered questionnaire surveys were administered which asked (mostly) the same questions. The first ran in Japan from 6th January to 10 January 2017 and was completed by 1,000 respondents who were evenly distributed by age band (20–60), gender, and region (Tokyo 23 ward, Aichi prefecture). The UK survey took place between the 16th to 22 March 2018 and was completed by 1,000 respondents, evenly distributed between London and the West Midlands and by age band, gender and region. The survey in Germany was applied in Berlin and the Ruhrgebiet between the 28th November and 7 December 2018 and comprised 1,000 responses that were evenly distributed by age band, gender and region. The distribution of all three surveys was subcontracted to a commercial research organisation called Rakuten Research (now Rakuten Insight – see https://insight.rakuten.co.jp/en/). Rakuten Insight maintains panels of members who are segmented by a whole range of personal, household, lifestyle, entertainment and health attributes who respond to

Table 1. Cultural dimensions in **Japan**, the UK and **Germany**. Range 0–100, source https://www.hofstede-insights.com/country-comparison/germany,japan,the-uk/.

Dimensions	Japan	UK	Germany	Comparison
Power Distance	54	35	35	JP>UK = DE
Individualism/Collectivism	46	89	67	UK>DE>JP
Masculinity/Femininity	95	66	66	JP>UK = DE
Uncertainty Avoidance	92	35	65	JP>DE>UK
Long/Short Term Orientation	88	51	83	JP = DE>UK
Indulgence/Restraint	42	61	40	UK>JP = DE

surveys in return for points which can be converted into vouchers. The surveys were administered under their own ethics and consent procedures.

3.2 Survey items and scale

The scale categories used for the online questionnaire survey are shown in Table 2. As can be seen, the various questions asked of the respondents fall into meaningful categories (e.g. we have used several variables (fear, ignorance, number of trips) which can be qualitatively summarized in context (e.g. car risk perception, fully AV individual perception). This was to keep the questionnaire concise and reduce the burden on respondents. The total number of driver and car passenger trips and the number of minutes were used to determine current travel behaviour. The respondents were then shown information about autonomous cars before being asked about their perception of the risk of AVs, determined from two questions relating to the levels of fear and familiarity ('I think they are frightening' (Dread/Fear) and 'I know it well' (the opposite of Unknown/Ignorance)), as suggested in Slovic (1987). Respondents were asked about their attitudes to the car and to partially autonomous vehicles from the perspectives of being a driver, car passenger and pedestrian, but only from car passenger and pedestrian perspectives for fully AVs since no driver is required. Regarding the 'Individual acceptance of AVs in society', as stated above, this relates to the level of approval or disapproval to 'an AV-dependent society'. The raw data from the surveys is available from the Loughborough University Data Repository at 10.17028/rd.lboro.16676773.

3.3 Principal component analysis (PCA)

A Principal Component Analysis (PCA) was performed to account for high correlations among independent var variance they shared, and they were grouped into appropriately labelled components. The Kaiser–Meyer–Olkin (KMO) measure was then used to get insight on whether the component analysis is useful and meaningful for our data. As such, values above 0.7 are satisfactory. The optimal number of components retained can be defined through a combination of various criteria such the Kaiser, Scree plot and the Variance. Rotation and more specifically, orthogonal rotation (Varimax), was selected to improve interpretability of the components as well as to ensure that the estimated components are not correlated (Osborne, 2015; Papadimitriou & Yannis, 2014; Theofilatos & Yannis, 2014). The component scores were then calculated to be used to input into the subsequent ordered logistic regression analysis. Finally, a reliability analysis was carried out to test the reliability of the components. More specifically, the Cronbach's Alpha was estimated for each component as an indicator of reliability. Values higher than 0.6–0.65 were considered satisfactory.

3.4 Ordered logit models

The dependent variable which is the individual AV acceptance has discrete ordered categories, and thus the ordered logit model specification is commonly used for this type of dependent variable, as in Eq. (1):

Table 2. Online questionnaire survey content and scales.

Contents	Scales and options
Frequency of car driving and passenger trips	We will ask you about your trips as a car driver and passenger this week. (Please fill in half-width numerals.) * Please write 1 for one way trip. ※ Please answer '0.5 hours' if the time is 1 to 59 minutes.
	[Total number of driving trips] How many trips did you make as a driver this week? [No of__ trips]
	[Total driving minutes] How many minutes did you drive for in total? _[In minutes]
	[Number of shared trips] How many trips did you drive with a passenger? __ [No of trips]
	[Shared trip minutes] How many shared minutes did you drive? _[In minutes]
	[Total number of trips as a car passenger] How many trips did you make as a car passenger? (Taxi excluded) _ [No of trips]
	[Total car passenger minutes] How many minutes did you ride a car (taxi excluded) _ [In minutes]
Car risk perception	[Risk perception from driver/passenger/pedestrian's point of views] Please imagine as you are a car driver/passenger/pedestrian. (From each point of view of driver, passenger and pedestrian); 5 point scale [1: strongly disagree, 5: strongly agree]
	[Fear] Do you think cars are frightening? [1: strongly disagree, 5: strongly agree]
	[Ignorance] Do you think you are well informed about cars? [1: strongly disagree, 5: strongly agree]
Partial AV Individual perception	The term "partially automated driving" refers to partially automated cars. (Table 1 is presented.); 5 point scale (1: strongly disagree, 5: strongly agree)
	■ We will ask your perception about automated driving. Please answer on the basis of partially automated driving (driver partially involved in driving).
	[Individual acceptance] Do you agree or disagree with "a partially automated driving society" future? [1: strongly disagree, 5: strongly agree]
	[Risk perception from passenger/pedestrian's point of views] Please imagine as you are a driver/passenger/pedestrian. (From each point of view of driver, passenger and pedestrian) [1: strongly disagree, 5: strongly agree]
	[Fear] Do you think a partially automated driving future is frightening? [1: strongly disagree, 5: strongly agree]
	[Ignorance] Do you think you are well informed about partially automated driving? [1: strongly disagree, 5: strongly agree]
Fully AV Individual perception	The term "fully automated driving" refers to fully driverless cars. (Table 1 is presented.); 5 point scale (1: strongly disagree, 5: strongly agree)
	■ We will ask your perception about automated driving. Please answer on the basis of a fully automated driving future.
	[Individual acceptance] Do you agree or disagree with "a fully automated driving society" future? [1: strongly disagree, 5: strongly agree]
	[Risk perception from passenger/pedestrian's point of views] Please imagine as you are a passenger/pedestrian. (From each point of view of passenger and pedestrian) [1: strongly disagree, 5: strongly agree]
	[Fear] Do you think a fully automated driving future is frightening? [1: strongly disagree, 5: strongly agree]
	[Ignorance] Do you think you are well informed about fully automated driving? [1: strongly disagree, 5: strongly agree]

$$y_i^* = \beta_{0(n)} + \sum \beta_i x_i \varepsilon_i \qquad \text{Eq.(1)}$$

where y_i^* is the latent (unobserved) variable measuring the response of respondent i, x_i is a (m × 1) vector of observed non-stochastic explanatory variables measuring the attributes of the respondent (i), β_i is a (m × 1) vector of unknown fixed parameters and ε_i is a random error term. The actual dependent variable y_i^* is unobserved and therefore standard regression techniques cannot be performed but instead, the observed variable y_i is included in the data, as the ordered variable described earlier. The relationship between the observed and the actual dependent variable is described as follows:

$$y = \begin{cases} 0, & if \ y* \leq \beta_{01} \\ 1, & if \ \beta_{01} < y* \leq \beta_{02} \\ \dots \\ n, & if \ \beta_{0n} < y* \end{cases} \qquad \text{Eq.(2)}$$

where the threshold values $\beta_{01}, \beta_{02} \dots \beta_{0n}$ are unknown parameters to be estimated. The notation used in Equation (2) indicates that each response category has a different intercept value (i.e. it is the only term of the model to which the n subscript for categories is assigned). These intercepts or 'thresholds' for the response categories must be understood as the average cumulative log-odds for each category.

3.5 Coefficient comparisons

As a last step in our analysis, the beta coefficients of the various components which were produced at the ordered logit models were compared across the countries. To do that, we followed Paternoster et al. (1998) and Clogg et al. (1995) and we applied a Z-test by using the beta coefficients as well as their corresponding standard errors. The null hypothesis for the equality of the two beta coefficients (i.e. $\beta1 = \beta2$) will be tested against the alternative hypothesis at a 95% level of confidence.

4. Results of online questionnaire surveys

4.1 Preliminary analysis

Tables 3 and 4 display the Kruskal–Wallis H test results of difference in the individual acceptance of AVs between Germany, UK and Japan. The Kruskal–Wallis H test is a rank-based nonparametric test used when the variable of interest is on a continuous or ordinal scale and we would like to compare two or more independent groups.

The results show there is a significant difference between each of the three countries for both levels of automation. In Japan the acceptance of partial AVs (+252 from strongly agree and agree) is quite a bit higher than for fully AVs (+88) but both are positive overall; while in Germany there is a very negative opinion of partial AVs (−130 Disagree and Strongly disagree) which falls even more for fully AVs (−243). Meanwhile in the UK we see respondents are slightly negative about partial AVs (−27) but are actually a little less negative (in fact almost neutral) about fully AVs (−1). One observation to add here is that the acceptability of AVs has in general decreased as time has gone by: from being broadly positive in January 2017 (Japan), to being more neutral in March 2018 (UK), to being

Table 3. Result of Kruskal–Wallis H test; 'Individual acceptance of AVs in society' for partial AVs. ***: significant at 99% level.

Partial AV comparisons	Frequencies	Country			H test	
		Japan	UK	Germany	H	p
Individual acceptance	Strongly disagree	47	213	261	127.176	<0.001***
	Disagree	103	148	159		
	Neither	448	305	290		
	Agree	261	203	188		
	Strongly agree	141	131	102		

Table 4. Result of Kruskal–Wallis H test; 'Individual acceptance of AVs in society' for fully AVs. ***: significant at 99% level.

Fully AV comparisons	Frequencies	Japan	UK	Germany	H test	
					H	p
Individual acceptance	Strongly disagree	134	296	356	67.802	0.001***
	Disagree	150	128	145		
	Neither	414	269	241		
	Agree	185	176	133		
	Strongly agree	117	131	125		

negative in November/December 2018 (Germany). However, given the design of the study it is impossible to determine how significant an influence this time element is, if at all.

4.2 Dimensionality reduction

The Principal Component Analysis (PCA) indicated the optimum number of components (five) which appropriately summarize the input variables for each country. The KMO test that assessed the adequacy of the sample size was satisfactory for all three countries, as values were higher than 0.75–0.8 for all countries. Moreover, the total variance explained by the components was satisfactory, namely 73.1% for Japan, 80.7% for the UK and 79.8% for Germany. Table 5 illustrates the PCA results for Japan, UK and Germany respectively. Following the regression method for scores extraction, each produced component consists of as many component scores as the observations of the dataset. Overall, the PCA analyses indicated the same trends for all countries as the variables were grouped in the following components according to each component characteristics:

- Component 1: AV Expectations
- Component 2: AV Ignorance
- Component 3: Driver Exposure
- Component 4: AV Fear
- Component 5: Passenger Exposure

Table 5 shows how the components were made up in each case provides as a summary of the component analysis. More specifically, for each component we present the main variables that constitute each component (i.e. variables with high loadings) with the respective loadings. It was decided to suppress all component loadings less than 0.5 to make the interpretation substantially easier. Moreover, for each component the value of Cronbach's alpha is shown in order to assess the validity of the items/variables that constitute each component. In other words, how closely related are the variables in each component.

Interestingly, in breaking each of these down, there are some subtle differences as well as some clear similarities.

- For Component 1 (AV expectations), whilst convenience featured as most important in Japan, followed by happiness and then social issues, in both the UK and

Table 5. Overview of PCA for Japan, the UK and Germany.

Japan				UK				Germany			
Components	Variables	Loading	Cronbach's alpha	Components	Variables	Loading	Cronbach's alpha	Components	Variables	Loading	Cronbach's alpha
Component 1 'AV Expectations'	Expectation_fully_AV_convenience	0.879	α = 0.933	Component 1 'AV Expectations'	Expectation_partial_AV_happiness	0.913	α = 0.971	Component 1 'AV Expectations'	Expectation_fully_AV_happiness	0.91	α = 0.958
	Expectation_fully_AV_happiness	0.873			Expectation_fully_AV_happiness	0.913			Expectation_partial_AV_happiness	0.906	
	Expectation_partial_AV_convenience	0.848			Expectation_fully_AV_social_issues	0.913			Expectation_fully_AV_social_issues	0.884	
	Expectation_fully_AV_social_issues	0.843			Expectation_partial_AV_social_issues	0.906			Expectation_partial_AV_social_issues	0.883	
	Expectation_partial_AV_happiness	0.843			Expectation_partial_AV_convenience	0.904			Expectation_partial_AV_convenience	0.874	
	Expectation_partial_AV_social_issues	0.823			Expectation_fully_AV_convenience	0.9			Expectation_fully_AV_convenience	0.864	
Component 2 'AV Ignorance'	Risk_partial_AV_Pedestrian_Unknown	0.923	α = 0.882	Component 2 'AV Ignorance'	Risk_partial_AV_Pedestrian_Unknown	0.912	α = 0.922	Component 2 'AV Ignorance'	Risk_partial_AV_Pedestrian_Unknown	0.94	α = 0.947
	Risk_fully_AV_Pedestrian_Unknown	0.9			Risk_fully_AV_Pedestrian_Unknown	0.901			Risk_fully_AV_Pedestrian_Unknown	0.936	
	Risk_fully_AV_Driver_Unknown	0.868			Risk_partial_AV_Driver_Unknown	0.844			Risk_partial_AV_Driver_Unknown	0.9	
Component 3 'Driver Exposure'	Shared_trips_as_driver	0.845	α = 0.675	Component 3 'Driver Exposure'	Driver_trips	0.872	α = 0.725	Component 3 'Driving Exposure'	Shared_trips_as_driver	0.839	α = 0.739
	Shared_minutes_as_driver	0.805			Driver_minutes	0.787			Driving_trips	0.809	
	Driver_trips	0.75			Shared_trips_as_driver	0.631			Shared_minutes_as_driver	0.749	
	Driver_minutes	0.628			Shared_minutes_as_driver	0.503			Driving_hours	0.704	

(Continued)

Table 5. (Continued).

	Japan				UK				Germany		
Components	Variables	Loading	Cronbach's alpha	Components	Variables	Loading	Cronbach's alpha	Components	Variables	Loading	Cronbach's alpha
Component 4 'AV Fear'	Risk_partial_AV_ Pedestrian_Fear	0.881	α = 0.806	Component 4 'AV Fear'	Risk_partial_AV_ Pedestrian_Fear	0.934	α = 0.887	Component 4 'AV Fear'	Risk_partial_AV_ Pedestrian_Fear	0.919	α = 0.908
	Risk_partial_AV_ Driver_Fear	0.79			Risk_fully_AV_ Pedestrian_Fear	0.924			Risk_fully_AV_ Pedestrian_Fear	0.898	
	Risk_fully_AV_ Pedestrian_Fear	0.789			Risk_partial_AV_ Driver_Fear	0.804			Risk_partial_AV_ Driver_Fear	0.847	
Component 5 'Passenger Exposure'	Passenger_trips	0.908	α = 0.813	Component 5 'Passenger Exposure'	Passenger_minutes	0.914	α = 0.750	Component 5 'Passenger Exposure'	Passenger_hours	0.887	α = 0.741
	Passenger_minutes	0.9			Passenger_trips	0.791			Passenger_trips	0.83	
					Shared_minutes_as_driver	0.626					

Germany happiness and social issues trumped convenience. This suggests using different marketing 'hooks' for promoters of AVs in Japan compared with the UK and Germany.

- For component 2 (AV ignorance), this perhaps surprising and rather worrying result was that acceptance actually fell as knowledge of AVs increased. Moreover, the ordering for all three countries was identical – with the strongest associations being with pedestrian risk (unknown) for partial AVs, then pedestrian risk (unknown) for fully AVs, and lastly driver risk (unknown) for partial AVs. The clear implication here is that current messages being picked up by the public are overwhelmingly negative, and that the sector clearly needs to work hard to change this perception so as to reassure people (especially pedestrians) as to the safety of AVs as a priority.
- For component 3 (driver exposure), in Japan the most influential factors were the driver of shared trips and shared minutes, followed by the driver trips and minutes – so the shared and then the trips aspects were predominant. By contrast in the UK it was driver trips and driver minutes, followed by driver of shared trips and shared minutes, meaning the driver and then the trips aspects were predominant. Finally for Germany, shared trips as driver and driver trips were followed by shared minutes as driver and minutes as driver – hence the trips and then the shared aspects were the most influential. This is fascinating and suggests that the most receptive niche in Japan to AV marketing are those who car share (who may also therefore be more open to driverless 'dial-a-pod'-style solutions), whilst in the UK the niche is lone drivers. For Germany, it indicates that frequent drivers who share their vehicles (as opposed to long distance lone drivers) may be the most accepting of AV messages.
- Component 4 (AV Fear) seems most influenced (understandably) by pedestrians – though marginally more of partial AV than fully AV in all cases which is surprising – and again highlights that much work is needed to reassure people that AVs are not a threat to them when walking along a street.
- Finally, component 5 (passenger exposure) has passenger trips followed by passenger minutes in Japan and the opposite in Germany and the UK (plus shared minutes as driver in the latter case). This suggests there may be value in setting up events to expose non-drivers to AVs in a 'protected environment' which may serve to reassure the public and increase the level of acceptance.

4.3 Modelling AV acceptance

Afterwards, the identified components as well as other variables of interest, namely gender, age, region, car ownership and car licence were used as independent variables to predict individual acceptance of both partial and fully AV levels for Japan, the UK and Germany. Firstly, the components were tested for potential inter correlation by using the Pearson correlation. Then the VIF (Variance Inflation Factor) values for each variable were checked for each model. All the values were between 1,00 and 1,10 showing no multicollinearity issues as expected (values over 10,00 indicate multicollinearity issues). Consequently, no correlations were identified hence the components could be then entered in the ordered logit models. In order to assess the goodness of fit of the model various types of pseudo R-square were considered, such as the Cox and Snell, the

Nagelkerke and the McFadden R-square. In the event for the goodness of fit, Table 6 illustrates that the pseudo R-square values are very satisfactory for both AV technology levels (particularly for fully AVs) and for all countries (especially the UK). One point to note here is that there are multiple associations between socioeconomic and demographic variables and attitudes that are not addressed in this paper, and this is a limitation.

Next, Table 7 summarizes the coefficients Beta, the standard errors (S.E.), the Wald values, the p-values and the significance of each variable. Specifically, it finds the following results.

For the partial AV Japan case, the positive sign of the beta coefficient of Component 1 means that high scores (i.e. high expectations of AVs in terms of happiness, social issues and expectations) are associated with higher probability to accept partial AVs. Similarly, Component 3 (driving exposure) has a positive sign of the beta coefficient, meaning that high scores (high driver-escort exposure) are associated with higher probability to accept partial AVs. On the other hand, the negative sign of Component 4 indicates that less AV fear increases the probability of accepting partial AVs. The fully AV model for Japan is slightly different. Although Components 1 (AV expectations) and 4 (AV fear) have a similar effect, Component 3 (Driving exposure) is in this case insignificant, whilst the probability of fully AV acceptance is additionally influenced by Component 2 (AV ignorance). Moreover, this was the only model in which gender was included as a significant variable. More specifically, male respondents are more likely to accept fully AVs than females, a finding which Hulse et al. (2018) also found for the Japanese case. It is interesting to observe that other variables like region, car ownership, car licence were not found to be significant in any of the national models. In light of the findings of previous work (e.g. National Police Agency (2016), Haboucha et al. (2017), and Hulse et al. (2018)) this is surprising. What this means is that people's attitudes exert a much stronger influence on acceptance than any socio-economic factor.

In the partial AV UK model, all five components were found to be statistically significant in predicting acceptance in the UK, and the explanation of the beta coefficients is similar to the models for Japan. Specifically, higher Component 1 scores (high AV expectations) are associated with a higher probability to accept partial AVs. Higher Component 2 scores (those with less knowledge of AVs) are also more likely to result in higher probability to accept partial AVs. Lower AV fear is correlated with higher likelihood of partial AVs acceptance. Moreover, respondents who have higher Component 4 scores (more driving exposure) are more likely to accept partial AVs, as are people with higher Component 5 (high passenger exposure) scores. Next, the fully AV model for the UK again shows all five components being significant and with the same signs as for the partial UK AV model.

Table 6. Ordered logit model pseudo R-square values for partial AV and fully AV acceptance in Japan, the UK and Germany.

Level of AV	Pseudo R-square test applied	Japan	UK	Germany
Partial AV	Cox and Snell	0.530	0.691	0.627
	Nagelkerke	0.566	0.722	0.656
	McFadden	0.274	0.373	0.317
Fully AV	Cox and Snell	0.611	0.794	0.619
	Nagelkerke	0.643	0.737	0.649
	McFadden	0.315	0.392	0.315

Table 7. Ordered logit model summaries for partial AV and fully AV acceptance in Japan, the UK and Germany. Note: *** is significant at 99%, ** at 95% and * at 90% level.

AV Level	Variables	Japan Estimate	Japan Std. Error	Japan Wald	Japan p-value		UK Estimate	UK Std. Error	UK Wald	UK p-value		Germany Estimate	Germany Std. Error	Germany Wald	Germany p-value
Partial AV	Thresholds 1|2	−4.86	0.232	440.688	<0.001***	1|2	−2.941	0.153	368.348	<0.001***	1|2	−2.226	0.121	336.53	<0.001***
	2|3	−2.804	0.144	380.374	<0.001***	2|3	−1.283	0.122	109.917	<0.001***	2|3	−0.687	0.099	48.059	<0.001***
	3|4	0.573	0.087	43.855	<0.001***	3|4	1.41	0.118	141.615	<0.001***	3|4	1.735	0.112	241.262	<0.001***
	4|5	2.842	0.137	433.231	<0.001***	4|5	4.03	0.189	457.036	<0.001***	4|5	4.023	0.179	505.305	<0.001***
	Variables Component 1	2.064	0.097	450.236	<0.001***	Component 1	2.801	0.123	521.413	<0.001***	Component 1	2.305	0.101	518.681	<0.001***
						Component 2	0.774	0.077	101.572	<0.001***	Component 2	0.357	0.069	26.772	<0.001***
	Component 3	0.132	0.073	3.234	0.072*	Component 3	−0.542	0.076	51.616	<0.001***	Component 3	0.154	0.065	5.546	0.019**
	Component 4	−0.508	0.071	51.688	<0.001***	Component 4	0.243	0.075	10.559	0.001***	Component 4	−0.897	0.072	153.275	<0.001***
						Component 5	0.202	0.072	7.791	0.005***					
Fully AV	Thresholds 1|2	−3.149	0.178	314.136	<0.001***	1|2	−2.183	0.139	244.886	<0.001***	1|2	−1.324	0.105	158.556	<0.001***
	2|3	−1.224	0.123	99.224	<0.001***	2|3	−0.746	0.117	40.917	<0.001***	2|3	−0.008	0.094	0.007	0.933
	3|4	1.681	0.129	169.601	<0.001***	3|4	1.797	0.127	200.571	<0.001***	3|4	1.957	0.116	286.049	<0.001***
	4|5	3.702	0.182	411.591	<0.001***	4|5	4.228	0.195	468.505	<0.001***	4|5	3.659	0.164	495.178	<0.001***
	Variables Component 1	2.407	0.107	503.511	<0.001***	Component 1	2.95	0.129	526.356	<0.001***	Component 1	2.269	0.102	499.011	<0.001***
	Component 2	0.227	0.072	10.084	<0.001***	Component 2	0.669	0.079	72.571	<0.001***	Component 2	0.361	0.072	24.941	<0.001***
						Component 3	−0.755	0.082	85.073	<0.001***	Component 3	0.156	0.066	5.638	0.018**
	Component 4	−0.653	0.073	79.116	<0.001***	Component 4	0.27	0.079	11.834	<0.001***	Component 4	−0.953	0.076	155.326	<0.001***
						Component 5	0.243	0.074	10.7	<0.001***					
	Gender_male (Ref. category female)	0.509	0.141	13.051	<0.001***										

Meanwhile the partial AV model for Germany shows similar results to the UK, with the one difference being that Component 5 (passenger exposure) is insignificant, whilst the fully AV model for Germany also shows Components 1–4 being significant with the same signs as for the partial AV model.

4.4 Country comparisons

As a last part of the analysis, the beta coefficients of the similar components in the ordered logistic models were compared across countries to assess the magnitude of the effect. For instance, the AV expectations in UK were compared with the AV expectations in Germany and Japan. Table 8 illustrates the results of the country comparisons in terms of the impact of the components of AV acceptance. The results indicate whether a difference of the beta coefficient is statistically significant or not and which country experiences a stronger effect from that component. Hence, a difference in expectations, ignorance, fear and exposure is examined. One potential limitation here concerns the direct comparability between the scales applied in each country. This was problematic in part because the SAE definitions of the different levels of automation changed between the surveys. Beyond that however, any changes made to the attitudinal scales adopted for each of the surveys were minimal, and so we are confident in comparing these attributes across the three countries.

For the partial AV model, the effects of Components 1, 2 and 4 on individual acceptance are stronger in the UK than in either Germany or Japan. For Component 1 (AV expectations), there is no significant difference between Germany and Japan, for Component 2 (AV ignorance) there was no significant effect in Japan, whilst Component 4 (driver exposure) was more influential in Japan than Germany. Meanwhile, Component 3 (AV fear) was more influential in Japan than in either the UK or Germany – there was no significant difference between these countries. Component 5 (passenger exposure) was only significant in the UK, and so it was not possible to compare this with the other countries.

Interestingly, the fully AV model also showed that the effects of Components 1 (AV expectations), 2 (AV ignorance) and 4 (driver exposure) on individual acceptance being more influential than in the other surveys. This time however, there was no difference between Germany and Japan for Components 1 and 2, whilst for Component 4 the effect in Germany was stronger than in Japan. Component 3 was not significant in Japan, and here there was no difference between the UK and Germany. As for the partial model, Component 5 (passenger exposure) was only significant in the UK, and so it was not possible to compare this with the other countries.

Finally, when comparing fully autonomous with partial autonomous acceptance, modelling results are similar, though a few notable differences can be identified for Japan. Firstly, Component 2 (Ignorance) is positively associated with fully AV acceptance, however no association was found with partial AV acceptance. Interestingly, Japanese respondents with a fear of autonomy and autonomous vehicles tend to accept partial AVs, whilst this component was not found to significantly influence fully AVs. This suggests that Japanese respondents are more open and positive towards partial autonomy but are more sceptical towards fully AVs than respondents in the UK and Germany.

Table 8. Overview of Lowest AV level country comparisons.

Level	Component	Label	Japan beta coef	Japan std. error	UK beta coef	UK std. error	Germany beta coef	Germany std. error	Japan-UK Z-test value	Japan-UK Result	Japan-UK Comparisons	Japan-Germany Z-test value	Japan-Germany Result	Japan-Germany Comparisons	UK-Germany Z-test value	UK-Germany Result	UK-Germany Comparisons	All countries Rankings
Partial AV acceptance	Component 1	AV Expectations	2.064	0.097	2.801	0.123	2.305	0.101	4.705	significant	Japan<UK	1.721	non-significant	Japan = Germany	3.116	significant	UK>Germany	UK>Japan = Germany
	Component 2	Ignorance-Unknown	-	-	0.774	0.077	0.357	0.069	-	N/A	N/A	-	N/A	N/A	4.033	significant	UK>Germany	UK>Germany
	Component 3	Fear of Autonomous Vehicles	0.132	0.073	−0.542	0.076	0.154	0.065	6.396	significant	Japan>UK	10.036	significant	Japan>Germany	0.897	non-significant	UK = Germany	Japan>UK = Germany
	Component 4	Driving Exposure	−0.508	0.071	0.243	0.075	−0.897	0.072	7.272	significant	Japan<UK	6.877	significant	Japan<Germany	3.391	significant	UK>Germany	UK>Japan>Germany
	Component 5	Passenger Exposure	-	-	0.202	0.072	-	-	-	N/A	N/A	-	N/A	N/A	-	N/A	N/A	N/A
Fully AV acceptance	Component 1	AV Expectations	2.407	0.107	2.95	0.129	2.269	0.102	3.24	significant	Japan<UK	0.934	non-significant	Japan = Germany	4.141	significant	UK>Germany	UK>Japan = Germany
	Component 2	Ignorance-Unknown	0.227	0.072	0.669	0.079	0.361	0.072	4.135	significant	Japan<UK	1.316	non-significant	Japan = Germany	2.882	significant	UK>Germany	UK>Japan = Germany
	Component 3	Fear of Autonomous Vehicles	-	-	−0.755	0.082	0.156	0.066	-	N/A	N/A	-	N/A	N/A	1.107	non-significant	UK = Germany	UK = Germany
	Component 4	Driving Exposure	−0.653	0.073	0.27	0.079	−0.953	0.076	8.581	significant	Japan<UK	8.221	significant	Japan<Germany	1.771	non-significant	UK = Germany	UK = Germany>Japan
	Component 5	Passenger Exposure	-	-	0.243	0.074	-	-	-	N/A	N/A	-	N/A	N/A	-	N/A	N/A	N/A

In seeking to explain the national/cultural differences using Hofstede (2011), from the model the higher masculinity score for Japan could explain why gender was significant there but not in the UK or Germany. Beyond that, no sensible patterns emerge. Meanwhile from the preliminary results we saw that Japanese residents were broadly positive, UK residents were neutral, and German residents were broadly negative about AVs. From Table 1, the only dimensions that (almost) follow a broadly similar ordering are: (1) power distance, perhaps indicating that more hierarchical nations are more accepting of AVs than less hierarchical states; and (2) masculinity, whereby the two more feminine European countries (the UK and Germany) were less accepting of AVs than was more masculine Japan. Otherwise it is difficult to discern the influence of the individualism, uncertainty avoidance, long-term orientation or indulgence dimensions on the acceptance of AVs in this study. That said, the results of this study do align with those of European Commission (2020) which found both large differences in AV acceptance across EU nations and significant heterogeneity within each country, and particularly support those of Potoglou et al. (2020) who found that whilst Japanese citizens would pay a premium to use AVs, Europeans would need to be compensated.

5. Conclusions and implications for policy

5.1 Main findings

Three hypotheses were developed from the literature that focused on evaluating the acceptance of AVs in society and the associated risk perceptions and behavioural intentions towards AVs, which were then tested by an online questionnaire survey to 3,000 individuals in Japan, the UK and Germany. The main results of this research are as follows:

Acceptance of AVs and perception of risk

(a) Higher AV expectations were generally found to be associated with higher probability to accept AVs for the different levels of automation.

(b) Reducing levels of ignorance about AVs actually made people less likely to accept them, thus suggesting that current messaging is negative to some degree.

(c) The online questionnaire survey showed that there is a strong association between people's risk perception of AVs and their acceptance. This relationship varies depending on the technological level of AV.

Acceptance of AVs and individual circumstances

(d) For the Japanese data the statistical analysis showed a difference in how males and females perceive risk, with females more inclined to perceive themselves as being more frightened and unfamiliar than males. No such gender effects were identified in the UK or Germany. Additionally, no other socio-economic parameters proved significant.

(e) AV acceptance was found to vary depending on a person's current travel behaviour, with frequent drivers and passengers more likely to be supportive of AVs.

Acceptance of AVs and national culture

(f) There were significant cultural differences between the levels of acceptance between Japan (broadly positive), the UK (broadly neutral) and Germany (broadly negative). In explaining these attitudes, it could be that more hierarchical and more masculine nations are more accepting of AVs than less hierarchical and less masculine states. It is difficult to discern the influence of the individualism, uncertainty avoidance, long-term orientation or indulgence dimensions on the acceptance of AVs from the results of this study.

5.2 Implications for policy and practice and future research directions

These results have significant implications for policy and practice. In particular, this study suggests that while people's cultural context, attitudes and travel behaviours are meaningful predictors of AV acceptance, this is not likely the case for the socio-economic variables which were not found to be statistically significant. However, this should be interpreted with care as the causality from attitudes to acceptance can be less straightforward than with typical socio-economic variables. It is acknowledged that the causal relationships related to attitudes and acceptance may be more ambiguous than those for the conventional socioeconomic and demographic variables and this is an issue for future work.

Specifically, our results show that in order to enhance the acceptability of AVs amongst the public, AV operators should:

(a) Make efforts to raise (or at least maintain) expectations of AVs among the public, though great care should be taken to ensure that these are never unrealistic. This would have the most significant impact on acceptance.

(b) More positively engage with the public to combat the apparent generally negative perception of AVs on media platforms, perhaps through demonstration projects.

(c) Actively address the fears that AVs instil in pedestrians particularly, perhaps by limiting maximum speed settings on city streets or by further 'softening' the design of the front of the vehicle to minimise injuries to people if they are hit.

(d) Not explicitly target women or other specific *socio-economic* groups with tailored information (outside of Japan and other masculine societies).

(e) Target frequent car drivers and passengers with information about what AVs could do for them.

(f) Target governments and populations of countries where AVs already have a positive image about how their society could be improved.

(g) Utilization of more in-depth data, including more countries for comparisons as well as include more variables/items to measure attitudes, beliefs etc.

Application of more complex models that better target causal relationships.

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