Assessing Public Perception of Self-Driving Cars: the Autonomous Vehicle Acceptance Model

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ABSTRACT

We introduce the Autonomous Vehicle Acceptance Model (AVAM), a model of user acceptance for autonomous vehicles, adapted from existing models of user acceptance for generic technologies. A 26-item questionnaire is developed in accordance with the model and a survey conducted to evaluate 6 autonomy scenarios. In a pilot survey ($n = 54$) and follow-up survey ($n = 187$), the AVAM presented good internal consistency and replicated patterns from previous surveys. Results showed that users were less accepting of high autonomy levels and displayed significantly lower intention to use highly autonomous vehicles. We also assess expected driving engagement of hands, feet and eyes which are shown to be lower for full autonomy compared with all other autonomy levels. This highlighted that partial autonomy, regardless of level, is perceived to require uniformly higher driver engagement than full autonomy. These results can inform experts regarding public perception of autonomy across SAE levels. The AVAM and associated questionnaire enable standardised evaluation of AVs across studies, allowing for meaningful assessment of changes in perception over time and between different technologies.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; *User models*; Empirical studies in HCI.

KEYWORDS

Autonomous Cars, User Acceptance, Questionnaire, Acceptance Model, Methods of Engagement

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1 INTRODUCTION

Autonomous vehicle (AV) research is an area of great public interest at present, and vehicles with limited autonomous functionality are starting to be deployed around the world. Autonomous functionality is appearing in currently available consumer vehicles (such as assisted braking and Tesla autopilot [11]), but there is little evidence to suggest that users desire the widespread use of autonomous vehicles; in fact, there is some evidence to the contrary [21].

Most existing studies of public perception of AVs do not use established models of User Acceptance (UA). They are therefore difficult to make comparisons between or interpret in terms of UA [23–26]. These surveys often use industry descriptions of 'Levels of Autonomy' which may not be clear to participants, and which vary greatly between studies.

This paper presents the Autonomous Vehicle Acceptance Model (AVAM), which unifies current efforts in measuring public acceptance of Autonomous Vehicles. The AVAM combines elements of generic technology acceptance models, car acceptance models, and levels of autonomy. Rather than assessing levels of autonomy directly as defined by SAE [22] (one of the more widespread current representations of autonomy levels) concrete examples of vehicles relating to each level are presented. This enables participants to more clearly visualise hypothetical technologies, something which may have resulted in less informed responses in previous studies where scenarios/vehicles are not clearly explained [23–26].

With the AVAM, we aimed for high internal consistency and high re-usability. We deployed the AVAM in an initial survey of 187 participants, following a pilot study with 54 participants which resulted in revisions to the model. We compare our results with those of a 2014 survey of public opinion towards AVs conducted by Rödel et al. [21] in order to gain an impression of the external validity of our proposed model. The comparison is qualitative, in absence of a full dataset from Rödel et al., reflecting generally on whether the AVAM captures trends similar to previous surveys. Our complete dataset is available upon request to enable proper comparison in future studies.

In addition to the introduction of the AVAM and assessment of its validity, we aim to investigate the implications of the results of our survey in terms of real-world user acceptance of AVs. Consequently, we hope to answer the question:

RQ1. How does user acceptance vary with the level of autonomy of a vehicle?

Further to user acceptance, prior work has shown that clarity of expected engagement with the driving task is required for all levels of autonomy [20]. Concretely: do users expect to require the use of their hands, feet, or eyes to manipulate a car in each autonomy level? This is not yet well addressed, despite being repeatedly posed by participants of prior studies [14, 19, 20]. We, therefore, include questionnaire items regarding the importance of these simple elements of physical interaction (hands, feet, eyes) in order to answer a second question:

RQ2. Which methods of control do users expect to have for vehicles with different levels of autonomy?

Following a review of relevant existing work, this paper is split into two key sections. Firstly the AVAM is introduced, with a discussion of its internal consistency and validity. Secondly, the results of our survey, conducted using the AVAM questionnaire, are considered in relation to the two research questions.

2 RELATED WORK

Autonomous Vehicles and Taxonomies of Automation

Features that can be considered low-level autonomy, such as cruise control and automatic parking, are already technically viable and commercially available. Some leading commercial examples of high-level automation projects include General Motors' Cruise Automation [9], Waymo from Google [27] and the highly publicised Autopilot from Tesla [11]. Many car manufacturers are also incorporating increased levels of autonomous functionality in their vehicles, as well as actively researching high-level autonomy [1, 5, 10]. More restricted autonomous vehicles confined to specific geographic regions, dubbed automated road transport systems, have also been piloted in a number of cities in Europe; examples include the CityMobil2 [2] and UK Autodrive [6] projects.

The NHTSA [17] and BASt [12] are two categorisations of AV developed by the US and German governments respectively. These have largely been consolidated into the SAE definition of six distinct levels of autonomy (Levels 0-5) [22]. These levels are intended to be precisely defined categories ranging from no automation to full automation. The categories are defined in terms of the *agent* responsible for the driving task—the human driver, or the automated driving system—as well as *subtasks* such as object and event detection and response.

While useful for the designers of autonomous vehicles, the SAE definitions can be unclear or even confusing from a user perspective [20]. Since user acceptance of vehicles depends strongly on their understanding of the autonomous functionality present in a vehicle, we argue that it is important to take a user-centred approach in such a definition. A user-centred categorisation of AVs will be critical in presenting meaningful descriptions of AVs to users in the future.

Models of User Acceptance

Various general models for user acceptance of technology have been developed. These help to quantify the acceptance of various technologies and enable easy comparison within a common framework. The Technology Acceptance Model (TAM) [8] was first described in 1989 and was subsequently expanded to form the TAM2 [28] in 2000. These models heavily influenced the 2003 Universal Theory of Usage and Acceptance of Technology (UTAUT) [29].

The UTAUT unified many existing models of user acceptance, aiming to explain users' intention to use a system and their subsequent usage behaviour. There are four key factors within this model: (1) *performance expectancy*, the degree to which an individual believes using the system will aid them; (2) *effort expectancy*, the degree of ease associated with the system; (3) *social influence*, the degree which an individual believes others think they should use the system and (4) *facilitating conditions*, the degree to which an individual believes there is organisational and infrastructural support for the system. Four further factors make up the remainder of the UTAUT: (5) *attitude toward using technology*, an individual's overall affective reaction upon using a system; (6) *self-efficacy*, a user's belief in their own ability and competence to use the technology; (7) *behavioural intention*, the degree to which the user intends to use the system and (8) *anxiety*, the degree to which a person responds to a situation with apprehension.

The UTAUT factors can be applied almost directly to user perception of autonomous vehicles. For example, the different autonomy levels can be compared in terms of users' *effort expectancy* (a highly autonomous vehicle might require lower effort to drive), or infrastructure tailored to autonomous vehicles may create *facilitating conditions* where users are more accepting of higher autonomy levels.

The Car Technology Acceptance Model (CTAM) [18] was designed specifically for cars. It introduces one additional factor over and above the eight UTAUT factors: (9) *perceived safety*, the degree to which an individual believes that using a system will affect their well-being. This factor is not relevant to the more general models aimed primarily at desktop software but is critical for vehicles. CTAM questions are worded to focus particularly on in-car technology, rather than whole car technologies such as AV.

These models provide a strong basis for assessing UA but are not directly applicable to AVs. Our model, the AVAM, incorporates these nine key factors of UA into a questionnaire worded specifically for evaluation of AVs.

Studies on the Acceptance of Autonomous Vehicles

Several studies have investigated public perception of various available autonomous driving technologies, as well as those predicted to become available in the future. Most of these use questionnaires, but do not incorporate formal models that distinguish factors related to user acceptance and experience. International surveys have been conducted but relied on participants conceptualising the established levels of autonomy [22] based on brief descriptions [23–26]. Others only used questions with a binary agree/disagree response for a constrained set of statements [13].

Some studies do apply aspects of these formal models to user acceptance of AV. Rödel et al. [21] used a number of factors from the CTAM, as well as the user experience factors *trust* [16] and *fun*. Madigan et al. [15] used the UTAUT to evaluate the acceptance of automated road transport systems in two cities in Europe. They found that the UTAUT constructs of performance expectancy, effort expectancy and social influence were all useful predictors of behavioural intention to use automated road transport systems. Zmud et al. [30] conducted a study again informed by the CTAM and UTAUT, but with an alternative quantitative questionnaire, in addition to qualitative questioning. None of these studies proposes a standard model for evaluating acceptance of AV, so are difficult to make comparisons between.

Therefore, we propose the AVAM as a standard model for user acceptance of autonomous vehicles. This would enable direct comparison between studies, allowing for changes in public perception over time to be evaluated, as well as more meaningful comparisons between specific vehicles or scenarios. Our emphasis on user-centric definitions is also useful for the communication of different categories to the non-expert end-users of these systems.

3 THE AUTONOMOUS VEHICLE ACCEPTANCE MODEL

The AVAM is an adaptation of the UTAUT [29] and CTAM [18] for autonomous vehicle technologies. It incorporates the eight complete factors of the UTAUT—Performance Expectancy, Effort Expectancy, Attitude Towards Technology, Social Influence, Facilitating conditions, Self-Efficacy, Anxiety and Behavioural Intention (to use the system)—as well as one factor introduced by the CTAM [18], Perceived Safety.

As in the CTAM, we propose that Anxiety, Self-Efficacy, Attitude Towards Technology and Perceived Safety are direct determinants of Behavioural Intention to use AVs, unlike the UTAUT where only Performance Expectancy, Effort Expectancy and Social Influence are considered as such. The motivation for the inclusion of these additional factors for technologies relating to cars is given by Osswald et al. [18]. A block diagram of the AVAM is shown in Figure 1.

Adapting the AVAM from these established models of UA provides a degree of implied validity. While the UTAUT was not developed with AV in mind, the model itself has been validated comprehensively, adapted and applied effectively to a variety of technologies, and been shown to be effective for measuring UA of some AVs [15]. Clearly, the constructs within such a model are transferable to the AV domain, but a standardised adaptation is of critical importance.

This section describes the questionnaire items and autonomy scenarios we develop, as well as the survey protocol and participants used for this study. The internal consistency and validity of the AVAM are then explored in the context of our survey.

Questionnaire

Our 26 item AVAM questionnaire—which uses 7-point Likert scales for responses, in line with the UTAUT—is shown in Table 1, along with an additional question relating to RQ2, regarding the importance of physical control over the vehicle. Answers to the three parts of this question are instead given on a 5 point Likert scale of importance, to aid simplicity.

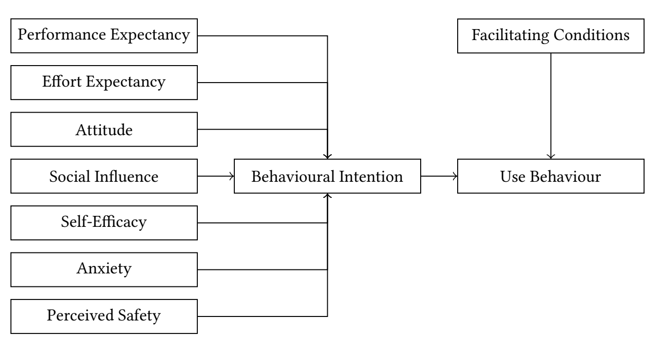

Figure 1: Block diagram of constituent factors of the AVAM.

Table 1: Questionnaire including 26 AVAM question items and question regarding importance of methods of physical control.

#	Question Text
Performance Expectancy	
1	Using the vehicle would enable me to reach my destination quickly.
2	Using the vehicle would enable me to reach my destination cost efficiently.
3	Using the vehicle would enable me to reach my destination safely.
Effort Expectancy	
4	I would find the vehicle easy to use.
5	My interaction with the vehicle would be clear and understandable.
6	It would be easy for me to learn to use the vehicle.
Social Influence	
7	I would be proud to show the vehicle to people who are close to me.
8	I would feel more inclined to use the vehicle if it was widely used by others.
9	I would prefer to use the vehicle with other passengers in the vehicle as well.
Facilitating Conditions	
10	I would have adequate control over the journey to my destination.
11	I have the knowledge necessary to use the vehicle.
12	The vehicle and infrastructure necessary to use the vehicle are practically feasible.
Attitude Towards (Using) Technology	
13	Using the vehicle would be a good idea.
14	The vehicle would make driving more interesting.
15	Using the vehicle would be fun.
Self-Efficacy	
16	I could reach my destination using the vehicle if I had just the built-in instruction for assistance.
17	I could reach my destination using the vehicle if I had no assistance.
18	I could reach my destination using the vehicle if there was someone who could help me.
Anxiety	
19	I would have concerns about using the vehicle.
20	The vehicle would be somewhat frightening to me.
21	I am afraid that I would not understand the vehicle.
Behavioural Intention (to use the Vehicle)	
22	Given that I had access to the vehicle, I predict that I would use it.
23	If the vehicle becomes available to me, I plan to obtain and use it.
Perceived Safety	
24	I believe that using the vehicle would be dangerous.
25	I would feel safe while using the vehicle.
26	I would trust the vehicle.
Methods of Control: How important would each of the following be when using the vehicle?	
1	Hands
2	Feet
3	Eyes

As described above, the key factors of the UTAUT and CTAM are used to structure the AVAM. Individual questions within the questionnaire are selected to correspond closely to their originating UTAUT factors. To make these relevant to AVs, rather than the originally intended desktop technologies, we largely take cues from the CTAM.

A question on expected utilisation of hands, feet, and eyes as methods of control is also included, in order to clarify in concrete terms how people envisage their expected engagement across levels of autonomy. This simple question has been posed by participants of prior studies [14, 19, 20], but has never been investigated in detail before. We use the term "eyes", as an element of visual attention, rather than the term "mind", which might imply a more complex engagement. This gives an indication of whether drivers feel that they need to visually supervise the vehicle, or whether they believe it to operate truly autonomously.

Finally, in order to gauge respondents typical driving behaviour, the questions "How often do you drive?", "For what reasons do you typically drive?" and "What type of journey do you typically take?" are asked prior to the main questionnaire, with participants able to choose multiple answers for the latter two. These questions, and their responses, are based on a previous study [20].

Autonomy Scenarios

Respondents were required to fill in the 26-item questionnaire six times, once for each of the six different "autonomy scenarios". These scenarios correspond directly to the six SAE autonomy levels. Each scenario is described in terms of the abilities of a hypothetical vehicle at that level of autonomy. Table 2 lists the autonomy scenarios. The scenario descriptions have a user-centric design; complex terms and acronyms used in the SAE definitions are removed or simplified while maintaining the core features of each level. Second person voice (e.g., "Your car can") is used to improve engagement and match the first person wording used in the AVAM question items.

The current definition of level 4 (hereafter abbreviated *L4*) autonomy is very broad; encompassing vehicles limited by geographic, environmental, traffic, speed, and temporal factors, as well as the type of roadway as used in our scenario. The scenario chosen to represent SAE L4 in this study corresponds to a vehicle which is autonomous on specific types of roadway; it represents an upgrade (which does not require driver fallback) of the L3 vehicle. Further analysis as part of this study showed there to be some significant differences between user perceptions of L4 vehicles based on the different limitations encompassed by the SAE definition. Thus, we acknowledge that this scenario does not fully represent the range of vehicles that fall into the L4 category,

Table 2: Autonomy scenarios, the descriptions presented to participants for different levels of autonomy.

Level 0: No Driving Automation Your car requires you to fully control steering, acceleration/deceleration and gear changes at all times while driving. No autonomous functionality is present.
Level 1: Driver Assistance Your car requires you to control steering and acceleration/deceleration on most roads. On large, multi-lane highways the vehicle is equipped with cruise-control which can maintain your desired speed, or match the speed of the vehicle to that of the vehicle in front, autonomously. You are required to maintain control of the steering at all times.
Level 2: Partial Driving Automation Your car requires you to control steering and acceleration/deceleration on most roads. On large, multi-lane highways the vehicle is equipped with cruise-control which can maintain your desired speed, or match the speed of the vehicle to that of the vehicle in front, autonomously. The car can also follow the highway's lane markings and change between lanes autonomously, but may require you to retake control with little or no warning in emergency situations.
Level 3: Conditional Driving Automation Your car can drive partially autonomously on large, multi-lane highways. You must manually steer and accelerate/decelerate when on minor roads, but upon entering a highway the car can take control and steer, accelerate/decelerate and switch lanes as appropriate. The car is aware of potential emergency situations, but if it encounters a confusing situation which it cannot handle autonomously then you will be alerted and must retake control within a few seconds. Upon reaching the exit of the highway the car indicates that you must retake control of the steering and speed control.
Level 4: High Driving Automation Your car can drive fully autonomously only on large, multi-lane highways. You must manually steer and accelerate/decelerate when on minor roads, but upon entering a highway the car can take full control and can steer, accelerate/decelerate and switch lanes as appropriate. The car does not rely on your input at all while on the highway. Upon reaching the exit of the highway the car indicates that you must retake control of the steering and speed control.
Level 5: Full Driving Automation Your car is fully autonomous. You are able to get into the car and instruct it where you would like to travel to, the car then carries out your desired route with no further interaction required from you. There are no steering or speed controls as driving occurs without any interaction from you.

but it does represent one of the most realistic interpretations based on current AV technology.

Survey Protocol

The survey was implemented using the online tool SurveyMonkey[1]. Participants were first presented with a brief description of the survey and basic demographic questions: age, gender, and country of residence. They were also asked if they possess a driving license and what their driving habits are using three questions based on [20].

Participants were then presented with separate, sequential pages for the six vehicles described in Table 2. The appropriate vehicle description was given at the top of each page (without mention of the SAE level or formal definition) and followed by the full AVAM questionnaire, with the questions from each factor of the model presented in separate blocks.

The order of vehicle descriptions and questions was kept constant for all participants. This may result in question order bias. However, Rödel et al. [21] found this to be preferable, as participants could more easily envision vehicles when the technologies featured became incrementally more hypothetical.

A pilot study ($n = 54$) was conducted prompting changes to the survey design and implementation; the autonomy scenarios and a number of the AVAM question items were reworded. Two items were also added to the AVAM questionnaire to better represent the underlying factors and provide improved internal consistency.

Participants

Participants were recruited through Amazon Mechanical Turk[2], which has been shown to provide respondents at least as diverse and reliable as conventional methods, if not more so [3, 4].

200 people completed the questionnaire. Data from 13 respondents was discarded as the completion time was under five minutes which we believed to be an unrealistic time for a participant to have properly read and responded to all questions.

The resulting 187 respondents had a minimum age of 22 and a maximum of 65. The mean age was 34 with a standard deviation of 9.2. 111 participants were male, and the remaining 76 female, all living in the United States of America. 181 of the participants possessed a driving license.

A reasonable distribution of driving behaviours was observed. Most participants drove at least once a week, with many driving every day. Driving was fairly evenly split between suburban, urban and highway environments, with somewhat fewer rural drivers. The majority of participants drove out of necessity, to commute to work or for everyday small trips.

[1]https://www.surveymonkey.com
[2]https://www.mturk.com

Table 3: Internal consistency of the AVAM questionnaire.

AVAM Factor	α
Performance Expectancy	0.857
Effort Expectancy	0.948
Attitude Towards Technology	0.815
Social Influence	0.906
Facilitating Conditions	0.893
Self-Efficacy	0.840
Anxiety	0.911
Behavioural Intention	0.956
Perceived Safety	0.863

Internal consistency

Table 3 shows the internal consistency for each factor of the AVAM based on our online survey, calculated using Cronbach's alpha [7]. All results are over 0.8 (good), with many above 0.9 (excellent).

External Validity

It is also important to consider the external validity of the AVAM questionnaire. In general, our survey results are concordant with those of existing studies [23–26], indicating that users are still reluctant to accept higher levels of autonomy. In particular, we consider comparison with one of the studies most similar to our own, that of Rödel et al. [21] in 2014 (henceforth the *2014 study*).

The 2014 study evaluated acceptance of vehicles using a taxonomy proposed by the National Highway Traffic Safety Administration (NHTSA) [17] (the NHTSA later adopted the SAE definitions). We map the five levels used in the 2014 study to the six SAE autonomy levels as follows: NHTSA L0, 1 and 2 corresponds directly to SAE L0, 1, and 2, NTHSA L3 corresponds to SAE L4, and NHTSA L4 corresponds to SAE L5. Effectively, SAE L3 is omitted from the comparison.

The 2014 study also assess slightly different factors of UA: Perceived Ease of Use, analogous to Effort Expectancy, and Perceived Behavioural Control, a constituent part of Facilitating Conditions. In addition, they consider Attitude Towards Technology and Behavioural Intention, which are assessed directly as part of this study. So, for comparative purposes, Perceived Ease of Use is evaluated from the three questions which make up Effort Expectancy in the AVAM, and Perceived Behavioural Control using Questions 10 and 11 in Table 1.

We acknowledge that there are a number of limitations in this comparison, as the scenario wording and question numbers and wording are still somewhat different, but comparison of the overall trends observed should serve as a sanity check of the results obtained using the AVAM questionnaire.

The results of the 2014 study are shown in a manner easily comparable to the results of our study in Figure 2. The implications of these on the external validity of the AVAM questionnaire are discussed briefly below. Results from our study corresponding to the nine AVAM factors mentioned above are summarised and discussed in full in the next section.

There is a general accordance in findings across all factors between the 2014 study and our results. Perceived Behavioural Control decreases at higher autonomy levels, highlighting a perception of lower driving engagement with more advanced AV technologies. A similar pattern occurs with Perceived Ease of Use, where higher autonomy levels actually create lower ratings. Similarly, Behavioural Intention and Attitude Towards Technology decreases in both studies as autonomy increases, also pointing to a lower trust in AV.

The similarity in the trends observed between these two studies, and others ([23–26]), indicates that the same underlying constructs are suitably encoded by the AVAM and are effectively evaluated by the AVAM questionnaire given in Table 1.

4 SURVEY RESULTS

In this section, we address the two research questions based on the results of our survey conducted using the AVAM questionnaire. Firstly, we consider the question "How does user acceptance vary with the level of autonomy of a vehicle?", and then the question "Which methods of control do users expect to have for vehicles with different levels of autonomy?". In response to each of these questions, we first present quantitative results, followed by a discussion. Finally, we summarise our findings in relation to the two research questions.

RQ1: Effect of Level of Autonomy

Results. Figure 3 includes results for all factors of the AVAM for each of the six SAE levels of autonomy.

All AVAM factors are significantly correlated with level of autonomy (Friedman test, $p < 0.001$). Performance Expectancy: $\chi^2 = 163.6$, Effort Expectancy: $\chi^2 = 434.1$, Social Influence: $\chi^2 = 20.6$, Facilitating Conditions: $\chi^2 = 664, 2$, Attitude Towards Technology: $\chi^2 = 216.9$, Self-Efficacy: $\chi^2 = 124.7$, Anxiety: $\chi^2 = 520.4$, Behavioural Intention: $\chi^2 = 394.0$, Perceived Safety: $\chi^2 = 479.2$. To assess whether differences between vehicles are significant the Wilcoxon signed-rank test (with correction) is used as the data is not normally distributed. A higher score represents a more positive sentiment in all cases except for Anxiety, where a higher score represents a more negative sentiment.

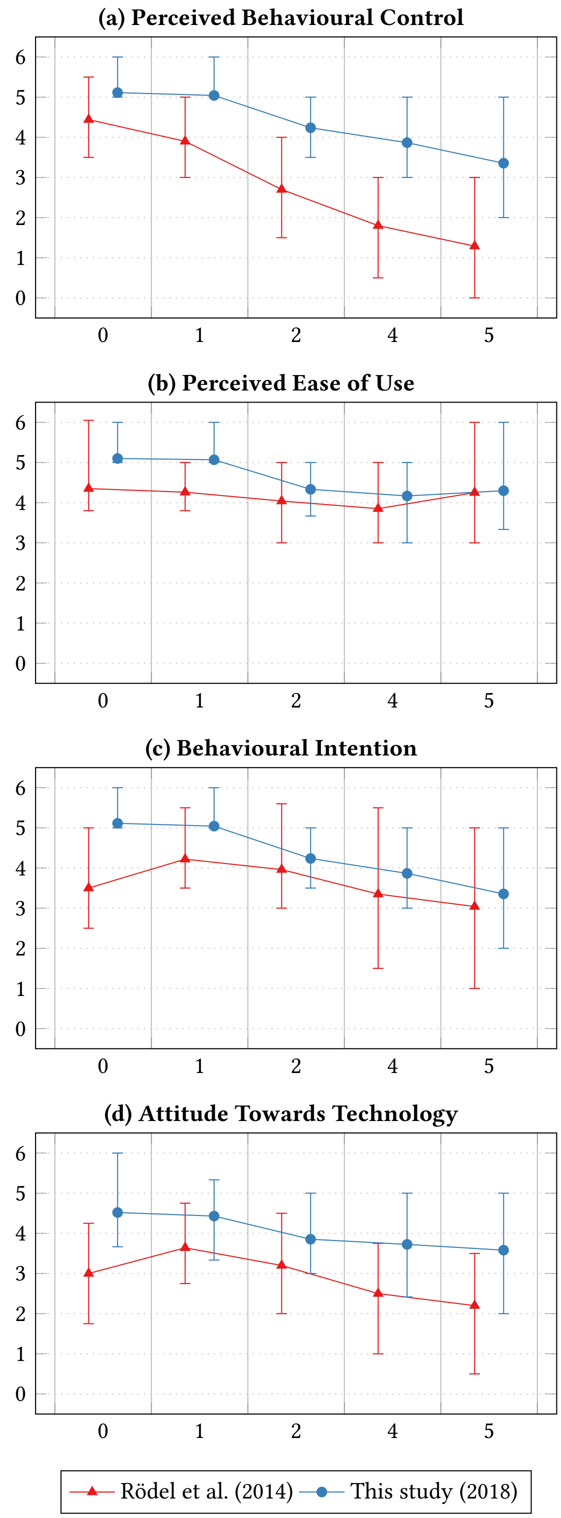

Figure 2: Various UA factors compared with the results of Rödel et al. [21]. In all cases y-axis represents rating and x-axis represents SAE level of autonomy.

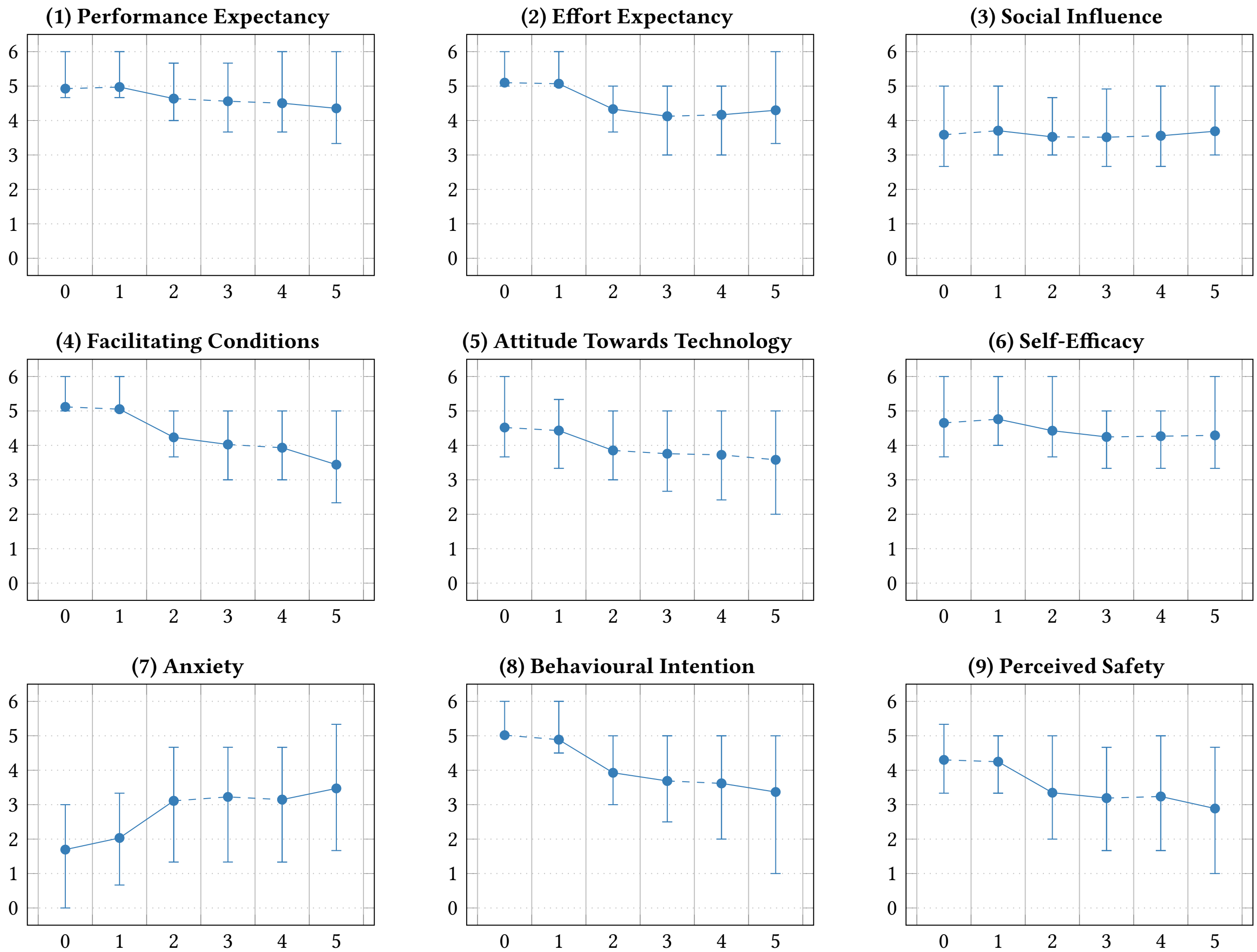

Figure 3: Ratings for each of the nine AVAM factors plotted against SAE level of autonomy. Solid lines indicate significant contrasts ($p < 0.01$). In all cases y-axis represents rating and x-axis represents SAE level of autonomy. Mean ratings are plotted, with the upper and lower quartiles averaged across the questions which make up the applicable AVAM factor also shown.

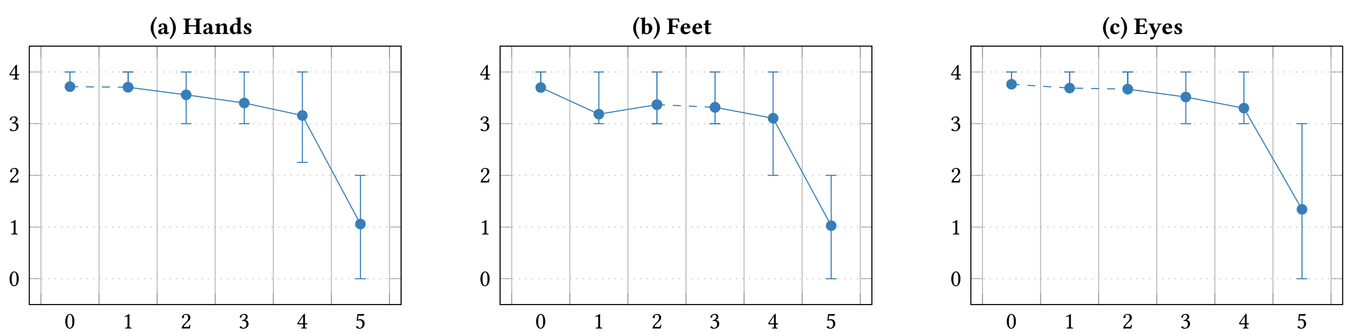

Figure 4: Importance ratings for methods of physical control over vehicles with different levels of autonomy. Solid lines indicate significant contrasts ($p < 0.01$). In all cases y-axis represents rating and x-axis represents SAE level of autonomy.

For Performance Expectancy, the decrease between L1 and L2 is significant ($p < 0.001$), as well as the decrease from L4 to L5 ($p < 0.01$). The decreases from L1 to L2 ($p < 0.001$) and from L2 to L3 ($p < 0.001$) in Effort Expectancy are significant, along with the increase from L4 to L5 ($p < 0.01$). For Social Influence, the decrease from L1 to L2 ($p < 0.01$) and the increase from L4 to L5 ($p < 0.01$) are significant.

Ratings for Facilitating Conditions decrease significantly between L1 and L2 ($p < 0.001$), L2 and L3 ($p < 0.001$) and between L4 and L5 ($p < 0.001$). The only significant contrast in Attitude Towards Technology is the decrease between L1 and L2 ($p < 0.001$), while Self-Efficacy decreases significantly from L1 to L2 ($p < 0.001$) and from L2 to L3 ($p < 0.001$).

Anxiety increases significantly form L0 to L1 ($p < 0.001$) and from L1 to L2 ($p < 0.001$), as well as from L4 to L5 ($p < 0.001$). For Behavioural Intention, the decreases from L1 to L2 is significant ($p < 0.001$) along with the decreases from L2 to L3 ($p < 0.001$) and L4 to L5 ($p < 0.001$). Perceived Safety also decreases significantly from L1 to L2 ($p < 0.001$), L2 to L3 ($p < 0.001$) and L4 to L5 ($p < 0.001$).

Discussion. The results of the AVAM questionnaire reflect that a general reservation of the public regarding AVs largely persists. Although not large in magnitude, effects of autonomy levels are still significant and will be discussed for each AVAM factor.

For Performance Expectancy, values reduce as automation increases, which is a seemingly counter-intuitive result, arguably reflecting the limited trust in this novel technology. This result might also indicate the safety concerns as automation increases, to be discussed below. Effort expectancy (i.e., perceived ease of use) generally reduces with higher automation up to L4, and then slightly increases in L5. Again, this might reveal the general lack of knowledge and trust in autonomous technology, though a slight benefit is recognised for full autonomy. Social Influence is relatively stable, with a slight decrease in intermediate levels, and an increase in L5. This could be an indication that using AV technology might be rewarding for early adopters.

As expected, Facilitating Conditions' ratings decrease as autonomy increases, revealing a public perception of AV technology being less ready for higher levels of autonomy. The same is true for Attitude Towards Technology and Self-Efficacy, ratings of which become more reserved with higher autonomy. Again, this arguably offers an accurate reflection of the novelty of AV technology.

The last three factors of the AVAM confirm the previously observed reservations of the public. Anxiety increases, and Behavioural Intention and Perceived Safety decrease with higher autonomy. It is interesting to observe that public opinion is still relatively reserved, also suggested by studies such as [23–26], despite the increasing prevalence of AVs on our roads.

We argue that more work is needed by experts to clarify the capabilities and limitations of AVs in order to increase trust in the technology. Taken together, the results of AVAM relate well to available literature, arguably providing a robust model of assessing perception towards AVs in a context of ever-increasing maturity of the technology.

RQ2: Methods of Control

Results. Figure 4 includes plots showing the importance ratings for each of hands, feet and eyes for vehicles ranging from L0 to L5 autonomy. In all cases, importance is significantly correlated with level of autonomy ($p < 0.001$). Hands: $\chi^2 = 479.0$, feet: $\chi^2 = 431.1$ and eyes: $\chi^2 = 448.0$.

Participants' rating of the importance hands decreases significantly from L1 to L2 ($p < 0.001$), L2 to L3 ($p = 0.001$), L3 to L4 ($p < 0.001$) and, most drastically, from L4 to L5 ($p < 0.001$). Feet instead see a significant decrease from L0 to L1 ($p < 0.001$), increase between L1 and L2 ($p < 0.01$), decrease from L3 to L4 ($p < 0.001$) and a pronounced decrease from L4 to L5 ($p < 0.001$). The importance of eyes decreases significantly from L2 to L3 ($p < 0.001$), L3 to L4 ($p < 0.001$) and again exhibits a major drop from L4 to L5 ($p < 0.001$).

Discussion. Figure 4 shows a sharp drop in the participants' perceived need to use hands, feet and eyes between operating L4 and L5 vehicles while remaining relatively constant between the previous levels of autonomy. This represents an interesting and novel, if not entirely surprising, finding.

The most likely explanation for this is that users perceive only two levels of autonomy: partial and full, without being able to differentiate well between different levels of partial autonomy. Furthermore, the same results seem to suggest that users perceive only L5 autonomy as appropriate for use by individuals that do not hold a driving licence or are otherwise unable to drive. Finally, the slightly higher mean, and higher spread of answers, for eyes compared to hands and feet indicates that users expect to have at least some level of supervision over the vehicle.

It is unknown to the authors whether (or to what extent) private, non-disclosed industry research has revealed similar insights. However, the results of this study could explain the current divide between technology companies and automotive manufacturers in developing vehicles of different levels of autonomy. Technology companies such as Waymo and Uber aiming to directly develop and introduce L5 autonomous vehicles in service of any individual, irrespective of whether they hold a driving licence. In contrast, automotive manufacturers such as Tesla or Audi are aiming to introduce autonomous features incrementally, addressing all levels of autonomy, in order for their products to still be competitive and technically viable before technological advances allow for L5 autonomy. In either case, we believe these findings could motivate further research on this topic and provide further insights about how to address user perception of different levels of autonomy and thus the user interfaces required to operate these vehicles.

General Remarks

The results of this study confirm previous observations that the public is yet to be fully convinced about autonomy in cars. Not only were participants more anxious about higher levels of autonomy, but they also reported lower expected performance and lower perceived ease-of-use. This is directly opposed to what we might expect based on the motivating factors in the development of AV. In accordance with these findings, attitude towards higher autonomy is rated lower, as is perceived safety, and participants' intention to use higher level autonomous vehicles is markedly lower. That said, ratings for higher level autonomy were still broadly positive, showing that while participants preferred lower autonomy, they were not completely averse to high-level autonomy.

Secondly, there was a clear difference of expectations in terms of the utilisation of hands, feet and eyes between L0–L4 and L5 autonomy. This is an important finding, indicating that, although real and valid technical differences exist across all autonomy levels, perceived user engagement does not escalate as clearly. *Some* expected engagement may be equally cumbersome regardless of how often it is required within L0–4 until it is not required at all in L5. This finding should inform expert approaches in communicating AV capabilities to the public, as well as efforts in simplifying human-machine interfaces across autonomy levels. The utility of AVs overall seems to be more appreciated in L5 according to this study, as was observed qualitatively by Politis et al. [20].

5 FUTURE WORK

The AVAM opens up scope for evaluation of many more causal factors of UA than are considered here; the focus on the primary research questions has led to the omission of many potential analyses. Breakdown by age, gender and driving experience similar to the analysis of the 2014 study [21] could provide many insights about variations in the acceptance of AVs.

In the future, it is possible that many people who are not already able to drive and are considering learning will have the option of buying an AV instead. The implications of having no prior knowledge of driving on the responses participants give to the AVAM questionnaire are sure to be dramatic. As such, it might be interesting to assess the opinions of current non-drivers instead of existing drivers, who constitute the majority of the sample considered in this paper.

There is also a clear limitation in selecting exclusively US residents as participants. Conducting further studies using the AVAM in other countries where AVs are becoming increasingly popular could provide interesting insights into cultural variation in the UA of new technologies. It is also possible that the use of Mechanical Turk has resulted in a bias towards participants more familiar with technology, future studies using the AVAM questionnaire should employ more diversely recruited samples.

The very nature of transport may also change entirely as a result of increased automation. Individual ownership may become less common, and use of public or shared-ownership transport rise. This might be driven by a rise in the price of vehicles due to complex autonomous features, or simply increased ease of use of public transport modalities. Consequently, a comparative evaluation of autonomy in different transport modalities, and from the passenger perspective, using the AVAM could be of interest.

It is also likely that our interactions with AVs will change significantly as the technology develops further. Interaction modalities such as voice and gesture are likely to become more widespread as the need for physical control diminishes. The AVAM can serve as a tool to evaluate the impact of these increasingly intelligent human-vehicle interfaces.

6 CONCLUSIONS

This paper has presented a model, the AVAM, for measuring user acceptance of autonomous vehicles in a standardised manner. This enables direct comparison between studies and allows for changes in perception of AVs over time to be assessed meaningfully.

The AVAM incorporates a 26-item questionnaire, paired with six scenarios that illustrate different levels of autonomy. The AVAM is adapted from established models of UA for desktop and in-car technologies and is broken down into nine key factors which are theorised to be meaningful dimensions in which to measure UA [18, 29]. We also incorporate a question to quantify expected physical engagement in order to clarify which interaction elements—hands, feet, or eyes—are perceived as most relevant across autonomy levels.

When tested with an online questionnaire, the AVAM showed high internal consistency and presented results consistent with prior research in the domain. Participants were generally positive about high-level autonomy, but ratings across almost all AVAM factors showed a significant preference for lower level autonomy. Most notable was the increase in anxiety associated with increasing autonomy, along with a corresponding reduction in perceived safety. Attitude towards L2–L5 AVs was lower than for L0–L1, as was participants' intention to use such vehicles, showing that acceptance of high-level autonomy is still a way off.

Expected engagement was substantially higher for L1–4 autonomy compared with L5, where expected engagement was lowest for all of hands, feet and eyes. This arguably presents a non-analogous escalation between technological robustness and expected driving engagement across autonomy levels. It seems that we have observed two general levels of perceived autonomy, namely partially-autonomous (L0–L4) and fully autonomous (L5). This finding can inform user experience design for AVs, highlight their expected utility, and clarify public expectations about this technology. Autonomous vehicles may serve best as an enabler and augmenter of capabilities in all autonomy levels, rather than a technology of escalating technical complexity, which only releases the user's full potential in the highest autonomy level.

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