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A Conceptual Model to Explain, Predict, and Improve User Acceptance of Driverless Vehicles

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ABSTRACT

This paper represents a synthesis of existing empirical acceptance studies on automated driving and scientific literature on technology acceptance. The objective of this paper is to study user acceptance of driverless vehicles that fall into SAE level 4, as they operate within the constraints of dedicated infrastructure. The review indicates that previous acceptance studies on automated driving are skewed towards car users, creating a need for targeted acceptance studies, including users of public transport. For obvious reasons previous studies targeted respondents who had not experienced driverless vehicles. As driverless vehicle are currently being demonstrated in pilot projects, we can now start to investigate their acceptance by users inside and outside of such vehicles. Addressing the multidimensional nature of acceptance, we develop a conceptual model that integrates a holistic and comprehensive set of variables to explain, predict and improve user acceptance of driverless vehicles. It links two dominant models from the technology acceptance management literature, the Unified Theory of Acceptance and Technology Use (UTAUT) and the Pleasure-Arousal-Dominance-Framework (PAD), with a number of external variables that are divided into system-specific, user and contextual characteristics.

Keywords: acceptance, driverless vehicles, human factors, full automation, real scenarios, test rides

INTRODUCTION

There are two main paths to vehicle automation. One is the evolutionary, incremental path of vehicle automation by the automotive industry, which is commercializing level 2 or partially-automated driving (SAE standard J3016). Under partially automated driving, the driver is not physically operating the vehicle, but supervises the system permanently to be able to resume manual control at any time *(1, 2)*. Recently, a number of Original Equipment Manufacturers (OEMs) have announced intentions to bring self-driving cars to market by 2020, with ”self-driving” meaning vehicles that assist rather than replace the driver.

The revolutionary approach towards full automation is represented by a number of projects, such as:

- Google’s self-driving minis, which have been running on closed test tracks in Mountain View in California (U.S.A.) and receiving ample media attention *(3)*,
- the EU-project CityMobil2 that implements automated road transport systems in several urban environments across Europe *(4)*,
- the LUTZ Pathfinder project in Milton Keynes (UK) that foresees the deployment of self-driving pods on footpaths and pedestrianized areas *(5)*, and
- the WEpods project, which develops two self-driving vehicles without a steering wheel or pedals. This project is in the Foodvalley region between the Ede/Wageningen railway station and Wageningen University and Research Centre (WUR) and also on the WUR campus in the Netherlands from mid 2016 onwards *(6)*.

The vehicles deployed within these projects fall into level 4 or highly-automated driving (HAD) in the SAE standard, defined as “the driving mode specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene” *(2)*. SAE level 4 vehicles can be regular vehicles (4R) or ‘pod’ like vehicles (4P) that each drive automatically in restricted conditions without any need for driver action. While 4R can be used in manual mode outside its operational range by a human driver, 4P can’t, because they are operated without a driver in the vehicle and can see some level of supervision by a control room. This paper focuses on user acceptance of these 4P vehicles, for which we will use the term “driverless” throughout the paper. In particular, we focus on driverless vehicles that function as feeder systems to public transport, where they can provide substantial cost reductions. Integrating public transport and driverless vehicles into a driverless transportation system could be the key breakthrough that radically spurs and pushes the development and commercialization of automated vehicles. This driverless transportation system would connect driverless vehicles to public transport as nodes in a dense, multidirectional and reciprocal network.

These driverless vehicles have a high potential to solve our transport-related problems such as congestion, energy dependency on oil resources, parking scarcity, pollution, noise, safety and a general degradation of the quality of social life *(7)*. This will be true in rural and urban areas, as they can provide seamless, on-demand, door-to-door and 24/7 mobility to all, including people who cannot drive due to age or physical limitations. However, if they are not accepted, their potentials to achieve the stated benefits will not be realized *(8, 9)*. This makes user acceptance very important, as it is a prerequisite for implementation success and determines whether they will be actually used. It would be unproductive to invest in designing and building these driverless vehicles if they will never be purchased and used *(10)*.

Previous research on user acceptance of automated driving has mainly studied user acceptance by conventional research methods (e.g. surveys, focus groups), often involving users without any real and concrete experiences with automated driving. Research studies on the general opinions, concerns and acceptance of automated driving *(1, 11, 12, 15-32)* largely neglected systems at SAE level 4 and 5. As driverless vehicles have not been commercialized yet, users have only a vague idea and cannot adequately imagine the possible interactions with and taking a ride in a driverless vehicle *(11)*. This limits the validity of previous user acceptance studies of automated driving *(12)*, as users tend to under- or overvalue new technologies with which they have not had any concrete and real experiences yet *(13)*, as the latter tend to be too psychologically distant and abstract *(14)*. Also, the majority of studies considered car drivers as the target population, because it is generally assumed that self-driving vehicles replace conventional vehicles. However, driverless vehicles also replace buses or trains, meaning that the perceptions of public transport users need to be taken into account as well. Other potential user groups that use, operate or make decisions about the implementation of driverless vehicles need to be considered as well in order to develop a holistic and comprehensive definition for the acceptance of driverless vehicles *(33)*.

Moreover, to compensate for the lack of real user experiences with driverless vehicles that may bias research results, most studies sampled lead users or users with vehicle automation experiences. This paper polls both first and late adopters, linking the evaluation of user acceptance to the technological life cycle.

To the best of our knowledge, no conceptual model is available that allows us to explain, predict and improve user acceptance of driverless vehicles. Therefore, we developed a conceptual model that represents the synthesis of existing acceptance studies on automated driving with scientific literature from other domains. The main benefit of this paper is that it presents a summary of the status quo of research on user acceptance of automated driving and translates this into a model, a step which has not been taken before. This model links two dominant models from the technology acceptance management literature with context-specific variables that are pivotal for the study of user acceptance of driverless vehicles. As a result, this study contributes to existing and creates new research on technology acceptance. It represents a basis for further validation and quantification by empirical research, including focus groups, interviews, questionnaires, and test rides with real users either using or encountering a driverless vehicle on real roads. The paper ends with a discussion and conclusion that critically reflect on what was achieved and learnt in this paper.

LITERATURE REVIEW

Existing acceptance studies on automated driving and the scientific literature from other domains give us valuable insights into the potential factors influencing user acceptance of driverless vehicles. The determinants of acceptance derive from the technology itself, from its users, and from the context in which it is embedded. Therefore, the drivers are divided into system-specific, individual and contextual characteristics. In a second step, these external variables are aligned with dominant models and variables that have been identified by the scientific literature.

ACCEPTANCE STUDIES ON AUTOMATED DRIVING

Conceptualization and Operationalization of Acceptance

The conceptualization of acceptance in this paper incorporates three levels: the user, the time perspective, and the different dimensions of acceptance. Regarding the user, this paper distinguishes between individual and societal acceptance that address two questions: First, is the individual user willing to accept and adopt driverless vehicles (individual acceptance)? Second, are we as a society ready to accept a traffic system with driverless vehicles (societal acceptance) *(12)*?

Second, the time perspective relates to the measurement of acceptance before, during, and after experiencing driverless vehicles. The assessment of acceptance before the user encounters a driverless vehicle defines potential acceptance as “prospective judgment of measures to be introduced in the future” *(34).*

Third, the dimensional nature of acceptance refers to Adell's *(33)* conceptualization of acceptance into five categories: (1) using the word accept, (2) satisfying needs and requirements of users and other stakeholders, (3) sum of all attitudes, (4) willingness to use, (5) and actual use.

In line with the first category, acceptance can involve the support or advocacy of driverless vehicles without actually using them (adoption).

The second and third categories relate to the perceived usefulness of and satisfaction with the system. These can be measured by Van der Laan et al.’s usefulness and satisfaction scale, which is the most commonly used instrument to operationalize acceptance and whose validity, reliability and robustness have been confirmed *(34, 35).* Additional indicators of acceptance falling into this category are efficiency, effectiveness and equity, whose relevance has been confirmed by studies in the driving domain *(36).* In particular, the inclusion of equity as the distribution of costs and benefits among affected parties is important. Including equity provides valuable insights when (penetration level) users would adopt driverless vehicles and for whom they would be the most beneficial. In this context, the inclusion of social acceptance as an indirect evaluation of the system consequences should be mentioned, because the debate of automated vehicles necessarily involves potential societal consequences, such as unemployment among bus or taxi drivers.

The fourth category, willingness to use, is usually operationalized by willingness to pay or by affordability. The willingness to pay questionnaire by Brookhuis, Uneken, and Nilsson is a common measurement. Its relevance has been corroborated within and across the domain of automated driving *(34).* Contrary to Vlassenroot and Brookhuis *(37),* we do not assume causal-order relationships between efficiency, effectiveness, equity, satisfaction, usefulness, and willingness to pay, because it is currently very difficult to determine the exact order of these indicators.

Finally, the conceptualization of acceptance, as built within the scope of this paper, should be linked to category 5 (actual usage) because, without actual usage, the benefits of driverless vehicles will not materialize *(9).* As they are still far from being available to the general public for everyday use, actual usage is operationalized by behavioral intention as a commonly used proxy variable for actual purchase or usage behavior *(38).* Behavioral intention measures the intensity or frequency of usage that users expect when driverless vehicles are commercialized.

SYSTEM-SPECIFIC CHARACTERISTICS

Unified Theory of Acceptance and Technology Use - UTAUT

This paper applies the Unified Theory of Acceptance and Use of Technology (UTAUT) that was developed by Venkatesh, Morris, Davis, and Davis *(38)* in a comprehensive review of eight of the most significant acceptance models. Their theory outperformed the previous eight models by accounting for 70% of the variance in use. The UTAUT incorporates four determinants of user acceptance: performance expectancy, effort expectancy, social influence and facilitating conditions *(34).* Its appropriateness for the study of user acceptance of driver assistance system has been confirmed *(35).*

Concerning performance expectancy, previous studies point to the perceived advantages of automated vehicles relating to different dimensions of users' driving performance: traffic safety, driver productivity, traffic flow, and fuel and emission efficiency. Investigating public opinion (n=1,533) in the US, UK and Australia, Schoettle and Sivak *(19)* found that respondents expected automated vehicles to lead to crash reduction (70%), fewer emissions (64%) and fuel consumption (72%), improved traffic congestion (52%) or reduced travel time (57%). Kockelman, Bansal, and Singh *(28)* identified three main issues that respondents associate most with automated vehicles: (1) equipment and system failure, (2) interactions with manually driven vehicles, and (3) affordability. Fewer crashes, lower emissions, and better fuel economy were the three main benefits respondents named, and these were almost equally weighted. The reduction in crashes, however, received the highest support with 63%. The ability of automated vehicles to reduce traffic congestion was questioned by 31% of respondents (n=347). Thus, we expect:

H1: Performance expectancy has a positive effect on acceptance.

The relevance of effort expectancy was corroborated by Kyriakidis, Happee, and De Winter *(1)*, who found that fully automated driving is perceived to be easier than manual driving and less difficult than partially- and highly-automated driving. This paper also assumes that driverless vehicles are easier to operate than either conventional cars or public transport, because they do not require any driver input apart from providing navigations via an interface that is intuitive and easy to use. This also explains why we drop "facilitating conditions" from the model, as the usage of driverless vehicles is mainly restricted to providing navigational input. The decision to omit "facilitating conditions" is in close agreement with a previous study, which utilized the UTAUT model to study user acceptance of driver assistance systems *(36).*

On the basis of these considerations, it is plausible to formulate the following hypothesis:

H2: Effort expectancy has a positive effect on acceptance.

There is only one study that we are aware of which studied the role of peer pressure effects (social influence) on the adoption of automated vehicles.

Kockelman, Bansal, and Singh *(28)* found that 50% of respondents (n=347) would prefer their family, friends, or neighbors to use automated vehicles before they adopt them. On the basis of the theoretical propositions that mode choice behavior is partly motivated by social norms and the strong role of the car as status symbol, a "private cocoon" and "sanctuary escape from the world" that provides flexibility, autonomy and an "interminable pull of sensory experience *(38),* we assume that:

H3: Social influence predicts the extent to which driverless vehicles are accepted.

Pleasure-Arousal-Dominance-Framework - PAD

The perception of product technology can be multidimensional and include a broad range of factors. In particular, the hedonic aspects of technology use can significantly impact the satisfaction of users at a level beyond its utilitarian aspects. To capture users' affective reactions to technology use, mood and emotions, this publication relies on Mehrabian and Russel's (1974) "Pleasure, Arousal and Dominance paradigm of affect (PAD)". This paradigm rests on three dimensions to measure the feelings of users: pleasure, arousal and dominance *(13).*

Achieving the "wow" factor when being driven by a driverless vehicle is a challenge, because driving is done by an inboard computer. Kyriakidis et al. *(1)* found that manual driving is considered to be the most fun part of driving and full automation is the least enjoyable mode. This was corroborated by Rödel, Stadler, Meschtscherjakov, and Tscheligi *(39)*, who describe fun as the degree to which using a specific system is enjoyable, and that the fun declines with higher levels of automation. The "wow" factor then relates to the multidimensional use of the space in driverless vehicles, which can be adjusted to the trip characteristics and user preferences. This addresses one of the most remarkable benefits of driverless vehicles: turning wasted driving time into a valuable economic asset. For example, a *commuting vehicle* picks people up sharing a similar route to work, in which the time a person is being driven can be used effectively, such as checking emails or holding phone conferences. A *yoga vehicle* can be a source of inspiration, an isle of the mind or creativity, which could be especially attractive for people in metropolitan areas. It can give employees of large business districts or campuses a moment to breathe and take a step back from their busy and hectic life and regain motivation. This will be translated into productivity and eventually firm growth. A *social networking vehicle* can connect people with similar (leisure) interests in different domains, such as culture, sports, clubbing or music. In this sense, the *social networking vehicle* has a social function, because it brings together people in urban areas, which will be pivotal in light of the increasing number of people moving into the cities and the resulting anonymity and social isolation. The rethinking of vehicle space that no longer serves the ultimate purpose of driving, but that can be used in multiple, more efficient ways may be one fundamental breakthrough to change the way we move, live and feel. In this way, driverless vehicles redefine the interaction between humans and their vehicle and the joy of being driven. In this vein, we assume that driverless vehicles are perceived to be both enjoyable and exiting and derive the following hypotheses:

H4: Pleasure has a positive effect on acceptance.

H5: Arousal has a positive effect on acceptance.

Dominance is equally applicable to driverless vehicles, because (driving) control is delegated to an inboard computer, and users will only indicate their desired destination. Some level of dominance can be provided by giving users at least the option to stop or redirect the vehicle at any time, to open the doors, while information on travel time and expected arrival will contribute to acceptance. Users shall develop trust in automation. Choi and Ji *(41)* define three dimensions of trust, which are system transparency, technical competence and situation management. System transparency is defined as the degree to which users can predict and understand the operation of automated vehicles. Technical competence relates to the degree of user perception on the performance of the automated vehicle. Situation management is the belief that the user can resume manual control in a situation whenever this is desired *(40).* Their findings point out that 47.4% of the variance in the adoption of automated vehicles was explained by these three dimensions. Thus, the issue of trust will relate to perceived safety, and to intuitive (expected) control strategies, including the interaction with other road users. This again relates to the automation, informing users and other road users of its intentions. (Trust will be further addressed below under “psychological characteristics”)

H6: Dominance and information will affect acceptance of driverless vehicles.

Vehicle Characteristics

Previous research studies document that user acceptance varies with the level of automation. Van der Laan et al. *(10)* predict that systems restricting driver’s behavior are less likely to be accepted than non-restrictive, informative systems. This is rejected by Kyriakidis et al. *(1)*, who found a higher willingness to pay for full than for high automation; however, it was supported by Schoettle and Sivak *(20),* who asked licensed drivers in the U.S.A. (n=505) about their preferred level of automation. In their study, 43.8% of respondents preferred no self-driving car, 40.6% a partially automated car, and 15.6% a completely self-driving car. 96.2% preferred to have actuators for manual control, such as a steering wheel, gas or brake pedals, in a completely self-driving car. Thus, we expect:

H7: Level of automation is negatively correlated with acceptance.

As was mentioned in the introduction, there are two types of automated vehicles: (1) conventional passenger vehicles transformed with built-in automation technology, and (2) driverless 4P vehicles with no steering wheel or pedals. This paper evaluates acceptance of both regular 4R and 4P vehicles to investigate the influence of vehicle type (brand) on user acceptance. Additional predictors on the propensity to adopt driverless vehicles include speed, size, access and service quality *(41).* The service quality indicators were adopted by the evaluation framework of the EU CityMobil project - the predecessor of CityMobil2. They comprise information (information availability and comprehensibility), ticketing (user satisfaction), cleanliness (perceived cleanliness), comfort (perceived comfort), privacy (perceived level of privacy) and perception of safety and security (perception of safety, fear of attack) *(42, 43).* We hypothesize the following:

H8: There are correlations between vehicle type, brand, speed, size, access, service quality and acceptance.

INDIVIDUAL CHARACTERISTICS

The importance of individual personal characteristics in the acceptance or rejection of automated driving *(44)* has been highlighted by prior acceptance studies on automated driving, as mentioned before. This paper divides individual personal characteristics into socio-demographic factors, psychological, and mobility characteristics.

Socio-Demographic Factors

Various researchers have conducted studies on automated driving systems in the past three years *(1, 11, 12, 15-32)*. These studies have consistently shown that men had a higher interest in automated driving than women, more positive attitudes towards automated driving, and a higher willingness to use and buy the technology. Kyriakidis et al. *(1)* revealed that men were less worried about automation failures and control than women, but were more concerned with liability issues *(24)*. Recently, the Eurobarometer survey on Autonomous Systems revealed that men feel more comfortable travelling in an automated vehicle "with little or no intervention by the human user" than do women (27% vs. 16%) (n=27,801) *(25)*. The only study that we are aware of that has shown a higher interest among women than men in using automated vehicles than men is the focus group study using 32 people from Los Angeles (CA), Chicago (IL), and Iselin (NJ) from the advisory services company KPMG *(17)*. However, in these studies women were generally underrepresented, which may bias research results and needs to be taken into account when interpreting results from studies on automated driving.

The reported effect of age on user acceptance of automated driving is also inconsistent. Kockelman, Bansal and Singh *(28)* found that elderly people have a lower willingness to pay for automated vehicles, probably because they are concerned about learning to use them and do not trust them. The global market research company Power & Associates *(11)* used a survey of 17,400 vehicle owners to study their willingness to purchase automated driving technology. The highest interest for fully automated driving came from men (25%) between 18 and 37 (30%) who live in urban areas (30%). The results of the second and third studies with over 15,000 respondents were in line with this study *(12, 13)*.

Ipsos MORI *(28)* conducted a survey with 1,001 British people between 16 and 75 years in June 2014. It was found that people living in congested cities found automated driving technology more important than people living in less urban environments. Doing focus groups with Berlin residents, Fraedrich and Lenz *(25)* found that spending time in the car for other secondary tasks has seen negative connotations for the achievement-oriented society, because a distinction between private and working time is more difficult to achieve. Study respondents point to the value of driving time, as it allows drivers to do only one task at a time with manual vehicle steering being a nice diversification from office work.

People with a higher income are most concerned with liability and less concerned with control issues, whereas lower-income people are more concerned with safety and control. Both lower and higher income people are concerned about costs *(24)*.

People with a higher income would be willing to pay more for their next vehicle and for vehicles equipped with automated driving features *(1)*. Closely related to this is the effect of education: people who finished their education at age 20 or older are more likely than those finishing their education at 15 or younger to feel comfortable traveling in an automated car (28% vs. 11%). This may correlate with employment status in that managers are the most likely and house persons the least likely to feel comfortable in an automated vehicle (31% vs. 15%) *(26)*.

The attractiveness of driverless vehicles for people too young to drive indicates that the family situation (e.g. number of children) explains some of the variation in the acceptance to use driverless vehicles. Research suggests that a higher number of children is positively correlated to the willingness to pay for driverless vehicles *(27)*. At the same time parents, are also worried about a driverless robot that chauffeurs their children around without supervision *(16)*.

Experience or familiarity with automation is likely to substantially influence acceptance. A majority at least stated that they have heard of automated vehicles *(25)*, which is in line with other acceptance studies *(17, 27)*. Kyriakidis et al. *(1)* found that people who currently use adaptive cruise control in their vehicles are more likely to pay for automated vehicles, as they feel more comfortable with the removal of the steering wheel and with data transmission. Study findings also point to the more positive attitudes of users about their driver assistance systems in their cars after actual experience with the systems *(45)*.

Familiarity and experience with automated vehicles may in turn relate to the tech-savviness of individuals *(27)*, suggesting that tech-savviness has a positive influence on acceptance.

Thus, it seems plausible to hypothesize:

> *H9: Young, tech-savvy, full-time male workers in urban areas with children in their household and experience with vehicle automation are likely to use driverless vehicles more frequently.*

Even though survey findings are diverse, we expect that driverless vehicles are especially attractive for customer segments that have been previously excluded from using a private vehicle. They may provide enhanced mobility and create functional benefits, which will be pivotal in acceptance, simply because they can make travelling feasible and affordable. Thus:

> *H10: Elderly people and people that are too young to legally drive a car are more likely to accept and use driverless vehicles.*

Mobility Characteristics

This paper assumes that the current mobility behavior of individuals influences their propensity to accept and use driverless vehicles. Cynganski, Fraedrich and Lenz *(46)* found that the activities respondents would engage in while in a fully automated car are similar to the ones they currently perform when driving a car, long-distance train or public transport. They include focusing on the ride and route, listening to music, chatting with other passengers, and enjoying the ride and scenery. Only a small percentage sees working in the car, surfing the internet, or watching movies as benefit of fully automated vehicles. This is in line with Kockelman et al. *(28)*, who found that 75% of respondents wanted to talk or text with friends and look out of the window while in a fully automated car. These findings contradict both of Autoscout24, which found 33% of study respondents wanted to use the car as mobile office *(25)* and of Kyriakidis et al. *(1)*, who found that the willingness to rest/sleep, watch movies, or read during fully automated driving substantially increases as compared to highly automated driving. Hence, it is reasonable to assume that:

> *H11: The productivity of driving time has a positive effect on acceptance.*

Kyriakidis et al. *(1)* also found that individuals who drive more would be willing to pay more for automated vehicles, which parallels the findings of Kockelman et al. *(28)* who found that individuals travelling more and living farther away from their workplace are more willing to pay for full rather than partial automation. Possession of a driver's license is negatively correlated with the likelihood to use automated vehicles, probably because individuals fear a loss of driving enjoyment, when automated vehicles become a common mode of transport *(25)*. This finding may correspond with the results of Bazilinskyy, Kyriakidis, and Winter *(41)* who analyzed 1,952 comments extracted from three online surveys with 8,862 respondents from 112 countries. They found that respondents who have a negative attitude towards automated driving also prefer to have manual vehicle control. Furthermore, we assume that the number of privately-owned cars is negatively related to the acceptance of driverless cars, because access to private mobility can reduce incentives to use driverless vehicles. The reverse should be the case for access to and frequency of using public transport (e.g. season ticket) which is likely to positively influence acceptance. The number of past crash experiences is positively correlated with individuals' willingness to pay for automated vehicles, indicating that such persons appreciate the enhanced safety benefits of these vehicles *(25)*. As a result, we hypothesize:

> *H12: Driving mileage, past crash experiences and access to and frequency of using public transport are positively and possession of a driver's license and private vehicle ownership negatively related to the acceptance of driverless vehicles.*

Psychological Characteristics

There are two driving-related psychological constructs that will be considered as potential determinants of user acceptance of driverless vehicles: locus of control (internal and external) and sensation seeking. Individuals with an internal locus of control tend to trust their own skills and abilities rather than an automated driving system, preferring to maintain direct involvement with the system regardless of how safe or reliable it is. Externals tend to believe they can't control external events that affect them and may be more willing to surrender control to the automated driving system and attribute the behavior of the vehicle to the system rather than to their own activities *(11, 43)*. Therefore, we expect that:

> *H13: Individuals with a strong internal locus of control are less likely to adopt driverless vehicles than individuals with a strong external locus of control.*

Sensation seeking is associated with a multitude of risky behaviors, such as gambling, smoking, and risky driving, including speeding and driving while intoxicated. High-sensation seekers tend to drive faster and less carefully with smaller distances between vehicles and with heavy braking *(13)*. For these people, delegating control to an automated driving system may lower the thrill and sensory experience of driving. In contrast to the assumptions by Payre et al. *(11)* and in line with Kyriakidis et al. *(1)*, we expect that:

> *H14: High-sensation seekers are less likely to accept and use driverless vehicles than are low-sensation seekers.*

A recent study by Choi and Ji *(41)* supports the claim that trust is a major determinant to predicting the reliance on and adoption of automated vehicles. The KPMG report *(16)* discovered that the discussions about fully automated cars were more on handling, safety, innovation and trust, and less on the power of the engine, transmission and styling. Bazilinskyy et al. *(41)* found that a portion of the population does not trust automated vehicles, indicating a negative attitude towards them. They prefer either manual or partially- automated to fully-automated driving. However, even though 9 respondents do not trust automated vehicles, they have a positive attitude towards automated driving *(24).* As driverless vehicles control vehicle steering, deceleration and acceleration, we hypothesize that:

> *H15: A high level of trust towards driverless vehicles is a requirement for acceptance.*

CONTEXTUAL CHARACTERISTICS

Introduction Scenario

This publication assumes that the manner in which automated vehicles are made available to the public influences the extent to which they will be accepted and used. Howard and Dai *(24)* revealed in their survey (n=107) that study participants believe that self-driving vehicles should operate with normal traffic (46%) or in separate lanes (38%), which parallels the results of Vöge and McDonald *(41)* who found that respondents were concerned about a mixed traffic situation between automated and manually driven vehicles or other road users. The Continental Mobility Study 2015 *(19)* 68% of the German (n=1,800) and 54% of the U.S. respondents (n=2,300) preferred to use automated driving in monotonous or stressful driving situations. This corresponds with the Continental Mobility 2013 *(18)*, which found that respondents would like to use automated driving on long freeway journeys (67%), in traffic jams (52%), on rural roads (36%) and in city traffic (34%). Payre et al. *(11)* found that 71% of respondents would like to use a fully automated vehicle when being impaired by alcohol, drug or medication. We hypothesize that:

> *H16: The traffic situation in which driverless vehicles are to be used accounts some of the variance in acceptance.*

National Differences

This paper evaluates user acceptance in the context of pilots within different countries. The relevance of cross-national differences for the acceptance of automated vehicles has been highlighted by studies on automated driving as mentioned before. Begg *(20)* surveyed over 3,500 London transport professionals on their perceptions of whether and how soon they expected automated vehicles to become a reality. 20% of respondents believed that fully-automated vehicles will commonplace in the UK by 2040, while the number of those who believed that this would not happen increased to 30%. Payre et al. *(11)* surveyed 421 French drivers and found that 68.1% of study respondents would adopt fully automated vehicles. Kyriakidis et al. *(1)* polled 5,000 respondents from 109 countries, finding that high-income countries were particularly uncomfortable with the transmission of their data to insurance companies, tax authorities or roadway organizations and were most concerned about software issues *(24)*. Also, they were more likely to have a negative and less likely to have a positive opinion about automated driving than people from low-income countries. On the basis of these results, we expect:

> *H17: High-income countries are less likely to accept and use driverless vehicles than are low income-countries.*

Conceptual Model

On the basis of the above considerations, we derive a conceptual model that consists of five blocks with multiple components. These are: external variables (socio-demographics, mobility characteristics, vehicle characteristics, contextual characteristics), psychological variables (locus of control, sensation seeking, trust), variables from the UTAUT model (performance expectancy, effort expectancy, social influence) the PAD framework (pleasure, arousal, dominance) and the acceptance construct (efficiency, effectiveness, equity, satisfaction, usefulness, willingness to pay, social acceptability, behavioral intention). In addition to the hypotheses stated above, this model assumes that there are relationships between the components of the model (these are depicted by arrows) and between the variables within the components (these are not depicted by arrows).

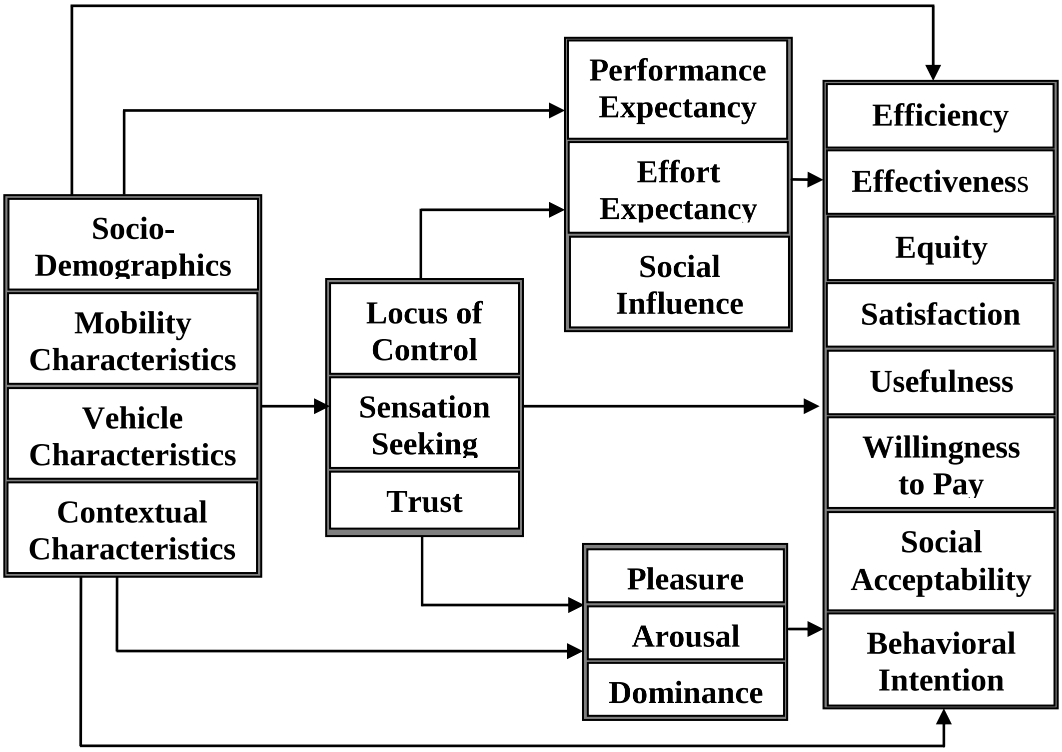

Figure 1. 4P Acceptance Model

DISCUSSION

To this point, we proposed a conceptual model theorizing the relationships between variables identified as a result of a synthesis on existing acceptance studies on automated driving and the scientific literature on technology acceptance. The model provides a detailed account of possible determinants of user acceptance that go beyond the mere attributes of driverless vehicles, but also include emotional and affective reactions to technology use. The model is currently descriptive and conceptual and may incorporate some built-in biases, as the current research on acceptance of automated driving is possibly skewed towards vehicle users that have not tested driverless vehicles. Therefore, in a next step, the model needs empirical validation and quantification involving users that not only use, but decide on and operate driverless vehicles. Users must involve not only potential early adopters and lead users, but also late adopters in order to make driverless vehicles a success. This is especially true in light of the heated debate on automated vehicles and potential consequences for society. One part of the empirical validation will take place by means of the WEpods pilot project, which will offer transport with driverless vehicles to ordinary customers on public roads, as mentioned in the introduction.

CONCLUSION

The available literature shows that the determinants of user acceptance of driverless vehicles are largely unknown. This is because previous acceptance studies on automated driving tend to focus either on automation levels lower than SAE level 4, often sampling users that have not had any concrete experiences with driverless vehicles. A conceptual model that explains acceptance of driverless vehicles is missing. Also missing is the incorporation of expectations and views of other stakeholders that are potentially involved in using, operating, or deciding on the implementation of driverless vehicles.

The main benefit of this paper is that it presents a summary of the status quo of acceptance studies on automated driving, which is translated into a conceptual model. This conceptual model has the advantage that it adopts a holistic and comprehensive view on user acceptance of driverless vehicles, because it identifies a relatively large number of factors that may determine user acceptance.

In addition, this paper proposed two new categories within SAE level 4 automation to distinguish regular vehicles (4R) from ‘pod’ like vehicles (4P) or the evolutionary from the revolutionary approach to vehicle automation.

The model will be validated by empirical research in the context of separate pilot studies, each of which revisits the model. We will perform qualitative research with potential users and non-users, private and public decision makers, and operators with experiences with driverless vehicles in order to learn more about their perceptions and views. Questionnaires will be distributed before, during, and after taking a ride in a driverless vehicle to test users’ reactions and changes in acceptance levels. Longitudinal changes in acceptance, users’ daily mobility behavior, and transport modes used will be investigated as well as long-term strategic implications for key players in public transport and the auto industry.

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