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Analyzing the models of consumer acceptance of technology from the perspective of preparedness for autonomous vehicles

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In our study, we review the framework of questionnaire research methods suitable for analyzing the consumer acceptance of vehicle industry innovations, more specifically, of autonomous vehicles. Our aim is to identify the most widely used research models and examine which variables affect consumer acceptance of self-driving technologies to the greatest extent. The various modified versions of the TAM and UTAUT models are the most commonly used models to address the topic in the literature. Both models are characterized by the attempt to predict a consumer's behavioral intention based on the specificities of a technology. Due to the difficulties of prior testing of self-driving technologies, it is worth reviewing these methods from the aspect of how suitable they are for capturing the consumer acceptance of this technology and through what adaptation measures. We do not aim to question the validity of researching the topic by questionnaire surveys, but we find it important to emphasize the significance of cautious adaptation. In the present paper, we intend to provide a methodological basis for future research related to autonomous technology by revising the TAM and UTAUT methods.

Keywords: autonomous vehicles, consumer acceptance, TAM, UTAUT

1. Introduction

Autonomous vehicles (AV) as a disruptive innovation will transform our daily lives in various ways. Whether it is a self-driving car, taxi, means of public transport, means of goods transport, last-mile delivery robot, or drone (Lukovics et al., 2018), an autonomous vehicle entails several potential benefits, from reducing harmful emissions and the number of parking places through defining more predictable departure and arrival times to the opportunities gained by spending less time driving. Nevertheless, a prerequisite of exploiting these opportunities is the consumer acceptance of autonomous technology and thereby its actual use (Cochen et al., 2020). It is especially important since the development level of the technology is at a much more advanced stage than its social acceptance. This is reflected in the fact that there are already several cities in the world where, even though on a testing basis, self-driving vehicles already travel the roads without a control of safety drivers, performing all the dynamic functions of driving completely autonomously (Cochen et al., 2018). On the other hand, there is no full social acceptance yet as many worry about how safe the use of AVs will be, who will be held legally responsible for an occasional accident, and what additional economic, societal, and ethical challenges the spread of AVs entails (Lukovics et al., 2023). Consequently, it is particularly important to explore the consumer acceptance of AVs, more specifically, its barriers (KPMG, 2018). Therefore, in our study, we overview the empirical methods which are specifically intended to examine the consumer acceptance of new technologies.

They mostly rely on logistic regression, and, in addition, we create latent variables from the variables based on modelling structured equations by using least squares method, while explaining the correlation between these variables (Kovács–Lukovics, 2022). Furthermore, we analyze the results obtained with the help of the presented research methodologies in the Hungarian and international literature in terms of the consumer acceptance of vehicle industry innovations.

In our study, first we present the evolution of the most widely used research models in the investigation of technology acceptance, the Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) in particular. We study how these models (and the variables they apply) can be adapted for an efficient analysis of autonomous technologies.

2. Prediction of consumer behavior

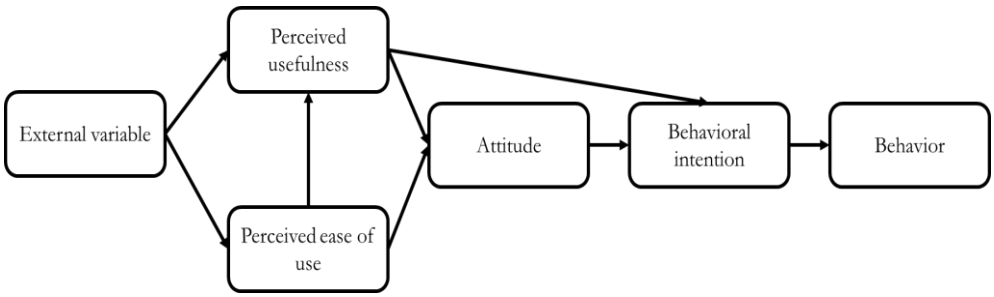
The pioneers of behavioral economics revealed that factors other than what is defined in rationality as interpreted by neoclassical economics also influence consumers in their decision-making processes (Zuti–Lukovics, 2023). These can be defined in various ways and can be internal factors characterizing an individual or specified aspects related to the subject of a studied behavior. Methodologies for examining the adaptation of behaviors can be found among the instruments of psychology. The majority of research methodologies used for analyzing the consumer acceptance of new technologies can be traced back to the Theory of Reasoned Action (TRA) created by Fishbein and Ajzen (1975) (Keszey–Zsukk, 2017). The authors point out that the adaptation of a given form of behavior can be derived from the Behavioral Intention characterizing individuals. It is directly affected by Attitude, which is a state of mental alertness and helps consumers simplify complex situations of decision making (Hofmeister, 2014), as well as by Subjective Norm, which refers to the combined effect of an individual's internal values and the environmental and social factors affecting them (Liu et al., 2019). Going further, Ajzen (1991) argues that behavioral intention cannot be an exclusive factor which influences actual behavior. Therefore, he includes an additional variable, Perceived Behavioral Control in the previously presented model, thereby creating the Theory of Planned Behavior (TPB). It relies on Bandura's (1977) Self-efficacy Theory, which, analyzing individuals' self-judgement, shows to what extent they consider themselves capable to acquire the competences required to exercise a studied form of behavior (Kaye et al., 2020).

In the last decades of the 20th century, several technological innovations occurred, such as the advancement of information technology, which not only fundamentally changed the way of performing standard activities, but their rapid spread necessitated the development of research methodologies which specifically enable analyzing the consumer acceptance of these technologies. In Section 3, we provide an overview of these methodologies, in each case addressing how and to what extent they can be adapted to investigating the consumer acceptance of autonomous technology.

3. Technology Acceptance Model (TAM)

Based on the TRA and TPB models, Davis (1989) created the first version of the Technology Acceptance Model (TAM), in which we can identify the constructions presented in the earlier models, i.e. the actual use of a new technology can be derived from behavioral intention, which is influenced by attitude. It is a novelty in the TAM 1 model (cf. Figure 1) that it defines the two variables influencing attitude, namely, Perceived Usefulness and Perceived Ease of Use. The former shows to what extent it makes an individual's daily life easier if they use the new technology in question, while the latter refers to how burdensome they consider the actual use and learning how to use it (Xu et al., 2018). On the one hand, this model can be easily adapted to self-driving technology since perceived usefulness (it facilitates an individual's mobility) and ease of use can be both well interpreted, but, on the other hand, it provides a rather narrow interpretation of potential influencing factors. The identification of more complex influences is carried out only later, in the TAM 2 and TAM 3 models.

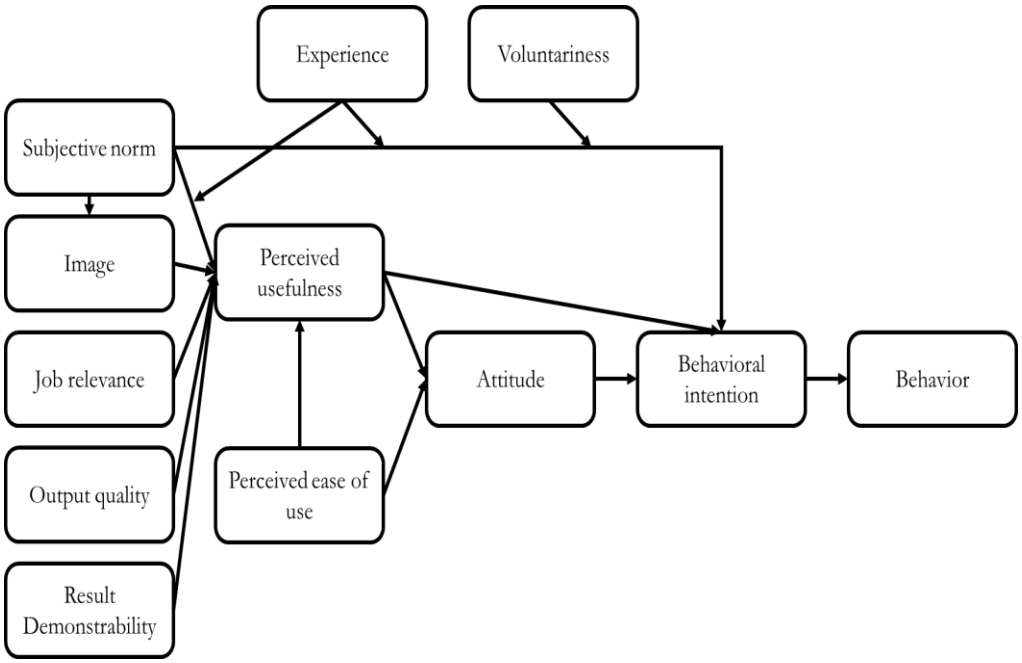
Figure 1. TAM 1 model



Source: Davis (1989)

The TAM 2 model (cf. Figure 2) was elaborated by Venkatesh and Davis (2000), in which they defined the factors influencing perceived usefulness. They claim that subjective norm, already featured in the TRA and TPB models, has a direct effect on behavioral intention, but it also influences perceived usefulness (Raue et al., 2019). This effect is moderated by Experience and Voluntariness. Moreover, it also affects perceived usefulness indirectly through Image with its direct influencing effect. As the TAM models were typically used for examining the acceptance of new technologies in a work environment, they incorporated variables which were specifically targeted at this purpose in the model (Csizmadia, 2019). These are Job Relevance, i.e. to what extent it is compatible with other work processes; Output, i.e. whether it actually leads to a better result; and Result Demonstrability, i.e. how the advantage generated by the use of the new technology can be captured. As this model primarily focuses on the technologies applied in a work environment, it is relatively difficult to adapt it to autonomous vehicles (especially in terms of factors such as "Job Relevance", "Output", and "Result Demonstrability").

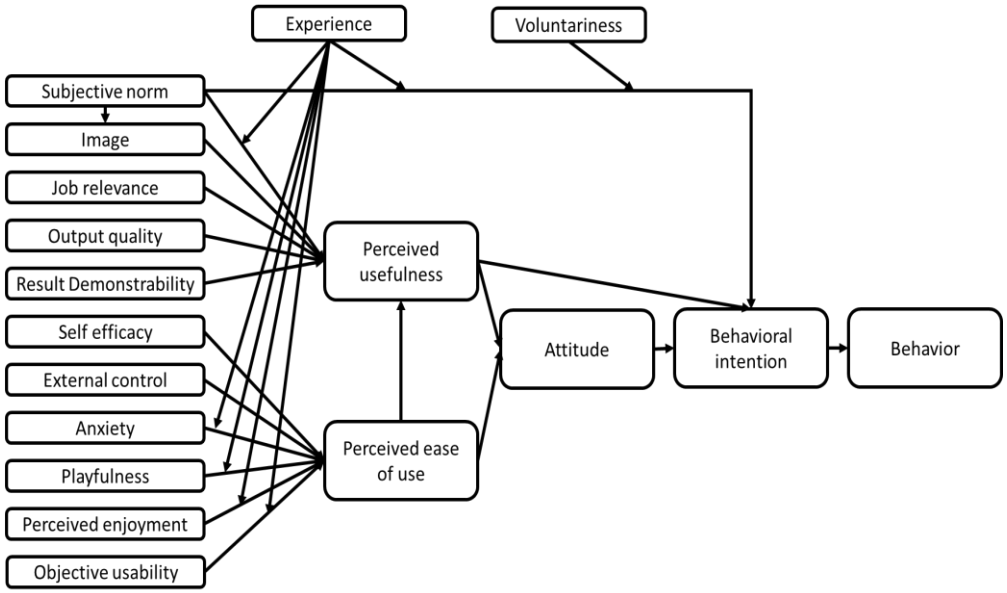
Figure 2. TAM 2 model



Source: Venkatesh–Davis (2000)

In the TAM 3 model (cf. Figure 3), Venkatesh and Bala (2008) included in total four behavioral anchors and two additional correction factors in the model to explain the perceived ease of use. The first behavioral anchor is Technological Self-efficacy, which shows that even though an individual is aware of their own abilities, there is no sufficient information about how difficult the use of a certain new technology will actually be (Strauch et al., 2019). The second anchor is Perceived External Control, which indicates the influencing power of workplace pressure and the support given there. The third anchor is Technological Anxiety, which analyzes an individual's openness to new technologies. Finally, the fourth is the Playfulness of the technology, which refers to how enjoyable it is to use the technology. The correction factors are Perceived Enjoyment and Objective Usability (Stephenson et al., 2020). On the one hand, this model can be better adapted to autonomous technology as it examines a sufficient number of factors the majority of which can be interpreted in terms of this technology, but, on the other hand, the above mentioned factors ("Job Relevance", "Output", and "Result Demonstrability") should still be left out of the model. By contrast, the new independent variables featured in TAM3 contribute to a more complex understanding of the consumer acceptance of autonomous technologies.

Figure 3. TAM 3 model



Source: Venkatesh–Bala (2008)

4. Practical application of technology acceptance models in investigating the consumer acceptance of vehicle industry innovations

Technology acceptance models have been used to examine the consumer acceptance of both self-driving vehicles and other vehicle industry innovations in several cases. At the same time, it is to be noted that the majority of these studies used the adaptation of the theoretical framework of the models with the inclusion of additional variables. We present some examples in the following section.

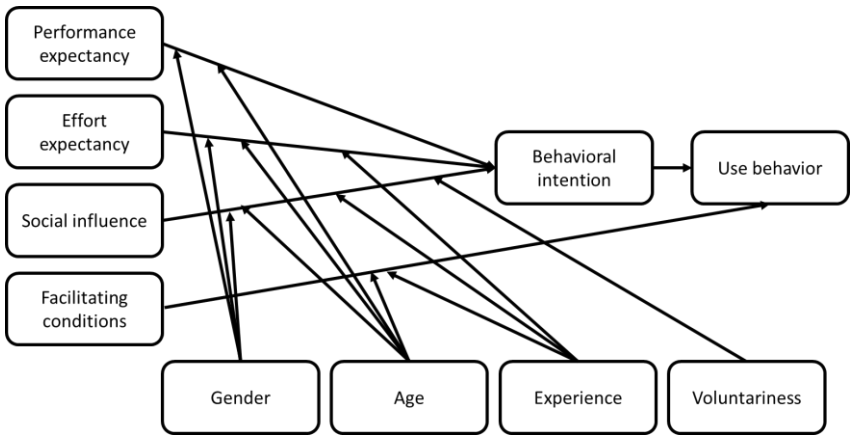
Studying the consumer acceptance of advanced driver assistance systems, Kaye et al. (2022) showed that perceived usefulness and perceived ease of use are both positive predictors of behavioral intention. Examining the public acceptance of connected vehicles, Acharya and Mekker (2022) pointed out that besides physical Safety, Data Protection and Data Security both positively influence behavioral intention. When analyzing the consumer acceptance of self-driving, Tan et al. (2022) highlighted the importance of Pleasure, Anxiety, and previous Knowledge in terms of behavioral intention. Jászberényi et al. (2022) studied the applicability of self-driving vehicles for touristic purposes, which also necessitates consumer acceptance. Therefore, they created their own model named TAMAT relying on the basis of TAM. Their results indicate that application for a touristic purpose and openness to unusual environmental elements have a positive effect on behavioral intention, while adherence to traditional solutions has a negative effect on it. Examining the consumer acceptance of electric vehicles, Wang et al. (2022) pointed out that Trust and Social Influence have a positive effect, while Perceived Threat has a negative effect on behavioral intention. In investigating the consumer acceptance of autonomous

vehicles, Koul and Eydgahi (2018) found that the number of years spent driving and age both have a negative effect on behavioral intention. Müller (2019) studied the consumer acceptance of electric and self-driving vehicles and mobility as a service in a system. He managed to show that the importance of Environmental Protection, Openness to innovation, Perceived Enjoyment, and Objective Usability are all significant influencers of behavioral intention.

5. Unified Theory of Acceptance and Use of Technology (UTAUT)

By synthesizing the previously known technology acceptance models, Venkatesh et al. (2003) created the Unified Theory of Acceptance and Use of Technology (UTAUT) (cf. Figure 4). They accept that behavioral intention directly affects actual use, but instead of a specific analysis of attitude, they define the factors influencing behavioral intention. These are Performance Expectancy, which is the overall advantages resulting from the use of the studied technology (Nistor et al., 2014); Effort Expectancy, i.e. the ease to learn how to use the technology (Guest et al., 2018); Social Influence, i.e. the assessment of the technology by those whose opinion has an effect on an individual's decisions (Kapser–Abdelrahman, 2020); and Facilitating Conditions, i.e. the external factors that facilitate the adaptation of the technology (Slade et al., 2015). The real novelty of the model is that its authors define moderator variables which moderate the effect of the independent variables influencing behavioral intention and actual use. These include Age, Gender, Experience gained by using similar technologies in the past, and Voluntariness (Venkatesh et al., 2016). This model is even more apparent to be adapted to the acceptance of autonomous technology compared to TAM 3 since "performance expectancy" means the benefit of the new form of mobility, while "effort expectancy" refers to learning and using the technology. "Social influence" can be interpreted as the social reactions the use of this technology will trigger. Finally, "facilitating conditions" indicates the availability of external conditions required for the adaptation of the technology.

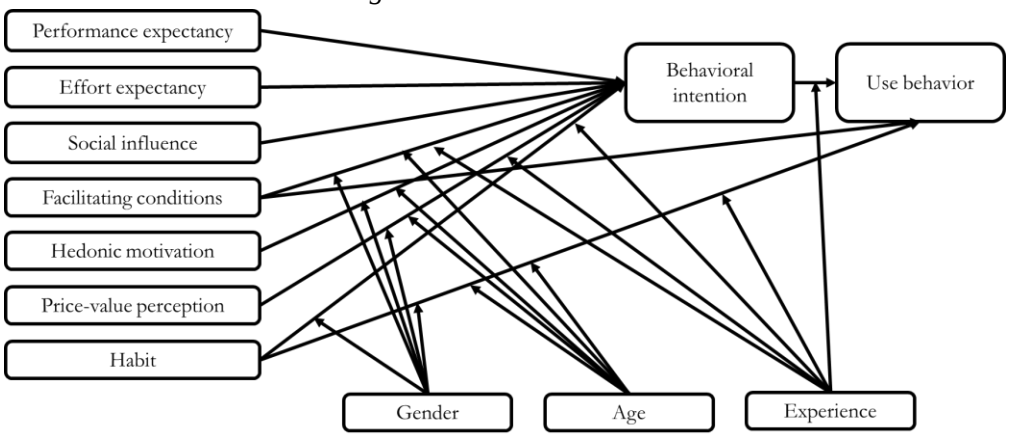
Figure 4. UTAUT Model



Source: Venkatesh et al. (2016)

Venkatesh et al. (2012) created the UTAUT 2 model (cf. Figure 5) to study the acceptance of new technologies for private use. They incorporate three additional variables in the previous UTAUT model. Hedonic Motivation tests the effect of convenience experienced during the use of a new technology and its enjoyment on behavioral intention (Kumar–Bervell, 2016). The examination of Price-value Perception is necessary because consumers must pay the costs of technology use on their own (Foroughi et al., 2023). Habit shows the effect of patterns developed during the use of similar technologies in the past on behavioral intention and actual use. The authors eliminated one of the previously defined moderator variables, voluntariness, from the model as in the case of technologies for private use, workplace pressure is not relevant, since the consumer makes the decision individually (Assaker et al., 2020). Among the above described models, this one is clearly the most suitable for a complex exploration of the acceptance of autonomous technologies. In addition to the adaptation of the independent variables featured in the UTAUT model, the new included variables can also be easily interpreted in the context of autonomous technology. "Hedonic motivation" refers to the experiential nature of travelling and use, while "habit" captures to what extent an individual's previous driving routine influences the intention of acceptance. Finally, "price-value perception" is evident in this area as well; the only detail to be added is that it is practical to analyze the renting costs instead of (besides) purchase.

Figure 5. UTAUT 2 model



Source: Venkatesh et al. (2012)

6. Practical application of the UTAUT in investigating the consumer acceptance of vehicle industry innovations

It is not surprising that UTAUT models have been used in studying the consumer acceptance of vehicle industry innovations in several cases. Similarly to the TAM models, a common feature of these studies is that the original model is extended with additional variables related to the technology in question.

Analyzing the consumer acceptance of self-driving vehicles, Adnan et al. (2018) found that ethical and legal issues have a significant effect on behavioral

intention. Studying the consumer acceptance of self-driving vehicles, Foroughi et al. (2023) assume the lack of price sensitivity. They claim that if self-driving vehicles are able to live up to the expectations attached to them, consumers will be willing to pay for the additional charge of the technology. They also point out that compatibility with already used technologies, trust, and image all influence behavioral intention. Examining consumers' willingness to purchase self-driving vehicles, Leicht et al. (2018) found that besides the variable they included in the model, which is openness to innovation, only performance expectancy, effort expectancy, and social influence have an effect on behavioral intention from the original UTAUT model. Madigan et al. (2017) studied the consumer acceptance of autonomous vehicles. Their results indicate that performance expectancy, effort expectancy, and social influence have the greatest effect on behavioral intention. Osswald et al. (2012) set up the Car Technology Acceptance Model (CTAM) using the framework of UTAUT. They omit all the moderator variables featured in the original model and include new independent variables influencing behavioral intention, namely, anxiety, self-efficacy, safety, and attitude towards new technologies. Analyzing the consumer acceptance of self-driving vehicles, Garidis et al. (2020) show the negative effect of losing the pleasure of driving on behavioral intention. When examining the consumer acceptance of self-driving buses, Cai et al. (2023) point out that performance expectancy, effort expectancy, social influence, and price collectively shape trust, which has a direct positive effect on behavioral intention. Goldbach et al. (2022) also investigated the consumer acceptance of self-driving buses. They revealed that besides performance expectancy and effort expectancy, trust and experience gained during the use of traditional public transport have a great effect on behavioral intention. Korkmaz et al. (2022) reached similar conclusions in examining the consumer acceptance of autonomous means of public transport, demonstrating the effect of experience gained during the use of traditional public transport on behavioral intention. Studying the consumer acceptance of autonomous means of public transport, Nordhoff et al. (2021) found that the compatibility with currently used modes of mobility has the greatest effect on behavioral intention. Investigating the public acceptance of driver state monitoring systems, Smyth et al. (2021) showed that performance expectancy, effort expectancy, social influence, and attitude all have a positive effect on behavioral intention. Finally, analyzing the consumer acceptance of advanced driver assistance systems, Cho et al. (2017) verified the influencing effect of trust, safety, and anxiety in terms of behavioral intention.

7. Discussion

It is a common feature in the results of the presented studies that they verify the usability of the applied methodology for capturing the consumer acceptance of autonomous vehicles. It is true for both the TAM and UTAUT models, moreover, that the obtained results are often in line with the research results which do not specifically use the framework of the two presented models. Kenesei et al. (2022) created their own PLS SEM model in the analysis of consumer trust and risk related to self-driving vehicles. They pointed out that trust towards regulatory institutions has no influence on the other variables included in the model, while trust towards manufacturers has a positive effect on data protection related to privacy, and, in addition, trust towards performance has a

positive influence on risk towards performance. In examining the acceptance of self-driving means of public transport, Launonen et al. (2021) showed that no failure of the autonomous system can be tolerated by consumers, and that trust and safety are of particular importance. Piegon et al. (2021) also highlight that performance expectancy, effort expectancy, safety, and vehicle characteristics are the most important regarding the consumer acceptance of self-driving means of public transport. Shi et al. (2021) reached a similar conclusion, drawing attention to the role of trust in the acceptance of autonomous vehicles. Also using their own model, Xiao and Gouillas (2022) identified the group of consumers who are the most willing to use autonomous vehicles, namely, those who already use innovative solutions in their daily lives, such as electric and hybrid vehicles, or have solar panels installed in their homes, which corresponds with the earlier defined openness to innovation. Finally, Zou et al. (2022) draw attention to the negative effect of nausea due to travelling by car regarding the consumer acceptance of self-driving vehicles.

8. Conclusions

In this study, we have reviewed the research frameworks primarily arrived at via questionnaire surveys, which are most commonly used in investigating the consumer acceptance of autonomous vehicles. We agree that although these methodologies can be used to capture the topic, we still need to consider some methodological limitations. In both the Hungarian and international literature, authors rely strictly on the dependent and independent variables defined in the original TAM and UTAUT models in the rarest of cases (Keszey, 2020). Instead, they include other, frequently similar variables in the models, or they occasionally eliminate variables from the original models (Prónay et al., 2022). The most commonly added variables regarding the consumer acceptance of vehicle industry innovations are knowledge, level of information, trust, social influence, policy, self-efficacy, ecological impacts, openness to innovations, compatibility, perceived threat, and perceived safety (Billanes–Enevoldsen, 2021; Nordhoff et al., 2019). Duboz et al. (2022) identified three main topics in terms of the consumer acceptance of autonomous vehicles: perceptions, expectations, and concerns.

It can be considered a further limitation that the procedures used for analysis can be perfectly applied in examining, for instance, satisfaction and loyalty, where the respondents already have experience about the subject of study. Nevertheless, the number of those who have real-life experience not only about self-driving vehicles, but also about the use of advanced driver assistance systems or other vehicle industry innovations is scarce (Lukovics et al., 2018).

Based on this, we have concluded that although a traditional questionnaire survey is suitable to study the consumer acceptance of autonomous vehicles, it needs to be completed to provide a deeper understanding. First of all, the respondents must be provided with the experience of traveling in a self-driving vehicle during the study, thus we suggest the application of experimental practices. Second, completing it with the use of cognitive neuroscience instruments, through empirical procedures, we could identify emotions such as anxiety, excitement, or overall emotional engagement, which have been proven to influence consumer acceptance (Lukovics et al., 2023). Third, it can also be useful to adapt research methods which are specifically suited to study consumer

preferences related to products still under development, such as the different versions of conjoint analysis (Ujházi, 2023).

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