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Development and validation of the Automated Vehicle Acceptance Questionnaire for Pedestrians (AVAQ-P)☆

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ABSTRACT

The investigation of automated vehicle acceptance (AVA) has received considerable attention in the past few years. Understanding the factors impacting their acceptance is pivotal to ensure a large-scale and wide acceptance of AVs. The AVA by pedestrians is still little understood. To address this knowledge gap, the main objective of this study is to develop and validate an instrument for the assessment of AVA by pedestrians. We tested this instrument on a German sample of pedestrians ($n = 136$), considering their individual demographic characteristics, and level of affinity for technology interaction. A four-step approach was adopted to analyze the data. First, a principal component analysis was performed to reduce the number of items, exploring the sources of variation in the dataset. Second, the principal components were subjected to a confirmatory factor analysis to investigate the validity and reliability of the proposed measurement model. Third, structural equation modeling was conducted to estimate the path relationships between our constructs. The study has revealed differences between the effect sizes and significance levels of the factors influencing pedestrians' AVA. The AVA by pedestrians was most strongly influenced by affinity for technology interaction (i.e., extent to which the individual actively approaches or avoids the interaction with new systems), performance expectancy (i.e., extent to which the individual believes that using the system will support them in achieving gains in the performance of the task) and social influence (i.e., extent to which the individual believes that people important to them think that the individual should perform the behavior). Male pedestrians were more likely to accept AVs. We also revealed significant interaction effects of age on the variables in our model. With this work, we have contributed to the development and validation of the Automated Vehicle Acceptance Questionnaire for Pedestrians (AVAQ-P). We recommend future research to replicate the study with a larger, more representative and gender-diverse population of pedestrians, considering cross-cultural differences in AVA.

1. Introduction

The investigation of automated vehicle acceptance (AVA) has received considerable attention in the past few years. Studies have

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examined AVA from the perspective of road users inside AVs, such as drivers and passengers, focusing less on the perspective of vulnerable road users (VRUs) (Das, 2021; Jayaraman et al., 2019; Li, Kaye, Afghari, & Oviedo-Trespalacios, 2023; Nair & Bhat, 2021; Rahman, Dey, Das, & Sherfinski, 2021). This is a concern because the acceptance and broad uptake of AVs does not only hinge on drivers or passengers but especially on external road users sharing space with AVs. An important group of vulnerable road users (VRUs) are pedestrians. With 20 % of involvement in fatal road crashes, pedestrians are more vulnerable than other VRU groups due to a lack of protective clothing, their low and vulnerable position on the road as well as their spontaneous and risky behavior towards other road users (European Commission, 2023). AVs have been proposed as potential solution to improve the safety of pedestrians (Deb et al., 2017; Kaye, Li, Oviedo-Trespalacios, & Pooyan Afghari, 2022). However, these and other benefits of this technology will only be realized if AVs are accepted by pedestrians (Kaye et al., 2022).

The AVA by pedestrians is still little understood. Acceptance is defined as an individual's willingness to use a system, and is typically measured by the intention to use a system (Adell, 2010). In order to promote the acceptance of AVs by pedestrians, it must be adequately measured and explained (see Bae et al., 2024). Until now, only a few instruments of AVA by pedestrians exist. Deb et al. (2017) developed an instrument for pedestrians' crossing intentions in front of AVs and acceptance, which originally included five main factors influencing pedestrians' behavioral intention to cross the road in front of AVs. These are attitude, social norms, trust, effectiveness and compatibility. Attitude captures positive or negative feelings towards AVs in general and specific advanced vehicle technology. Social norms capture the individual belief of what people important and influential to the individual think about AVs. Trust is the individual belief that an AV will perform its intended task with high effectiveness. Effectiveness refers to the extent to which an AV successfully detects pedestrians and other obstacles on the road, stops for them and/or allows safe pathway for them. Compatibility is the degree to which the AV is perceived as being consistent with the existing transportation system. The authors could only retain a three-factor structure consisting of safety, interaction and compatibility. Safety is defined as the successful control and operation of AVs on public roads. Interaction refers to pedestrians' confidence to cross the road in front of AVs (Deb et al., 2017). Gronier et al. (2024), however, could validate Deb et al.'s (2017) original five-factor structure among a French sample. Dommes et al. (2024) also validated Deb et al.'s (2017) questionnaire among a French sample and could neither produce the three-factor structure of Deb et al. (2017) nor the five-factor structure of Gronier et al. (2024). Instead, they identified a three-factor structure consisting of positive attitude, social norms and compatibility. The autonomous vehicle acceptability scale by Qu, Xu, Ge, Sun, & Zhang (2019) captures the perceived benefits and concerns associated with the deployment of AVs.

While these instruments substantially advance our understanding of the AVA by pedestrians, critical knowledge gaps remain.

First, prior AVA pedestrian questionnaires limit their explanation to a few key AVA factors, such as safety or attitude, neglecting other factors that are critical for AVA, such as trust and well-being/mental health. More specifically, the mental health/well-being aspect captures a more recent perspective in the AV domain – *"What's beyond safety?"* – that calls for researchers and designers in transportation to not only focus on ensuring safe interactions between road users and AVs but to also consider road users' well-being (Mehrotra et al., 2024).

Second, most prior instruments have limited their understanding of AV-pedestrian interaction to pedestrians' willingness to cross the road in front of AVs (Deb et al., 2017). However, not all pedestrians will directly interact with AVs and cross the road in front of them by the time they encounter them on public roads. Interaction between AVs and pedestrians can be much broader. In line with Li et al. (2023), we posit that an interaction occurs if pedestrians are influenced by the behavior of AVs "intending to occupy the same region of space at the same time in the near future", Markkula et al., 2020, p. 736).

Third, prior instruments do not explicitly establish the connection between needs and AVA. Drawing the connection between needs and user acceptance is important because designing AVs that satisfy user needs is critical for their adoption and thus their success (see Gould, & Lewis, 1985; Lidynia et al., 2021; Zarmpou et al., 2012). For this reason, our instrument derives from Maslow's hierarchy of needs (Maslow & Lewis, 1987). Maslow & Lewis (1987) distinguishe between five basic human needs, which "arrange themselves in hierarchies of pre-potency", which means that "the appearance of one need usually rests on the prior satisfaction of another" (p. 370). Thus, individuals will first strive to satisfy "lower needs" (i.e., needs organized at the bottom or lower levels of the pyramid) that are stronger than "higher needs" (i.e., needs organized at higher levels or the top of the pyramid) (Maslow, 1948). The five needs include physiological needs (e.g., food, water, shelter) at the bottom of the pyramid, the need for safety and security (e.g., health, employment) (the second-lowest layer of the pyramid), love and belonging (e.g., friendship, family) (the third-lowest layer of the pyramid), self-esteem (e.g., confidence, achievement) (the second-highest layer of the pyramid), and self-actualization (e.g., creativity, acceptance) (the top layer of the pyramid) (Maslow, 1943).

Despite the wide acceptance of Maslow's theory in different domains, no universal measurement of Maslow's five needs exists (Blonigen et al., 2024; Leidy, 1994; Wahba & Bridwell, 1976; Williams & Page, 1989). This has contributed to an unsystematic measurement of these needs (Kermavnar et al., 2024). The measurements that do exist – for example the scale for psychological security-insecurity (Maslow et al., 1945) – do not measure Maslow's (1943) hierarchy of needs holistically. Moreover, Maslow's theory has not been applied to the AV domain and more specifically to the AV-pedestrian interaction context. For this reason, little is known about the applicability of Maslow's theory in this important context.

To ensure that our instrument has a strong empirical foundation, we reviewed the empirical literature on AVA to identify, conceptualize and operationalize the needs of pedestrians in AV interactions. The literature that we reviewed to identify the needs is presented in Section 2 and Section 3.3 (Table 1). Hierarchically organized from the bottom to the top of the pyramid, we define pedestrian needs as safety and trust, performance expectancy, comfort and pleasure, social influence and mental health/well-being, as presented in Fig. 1. The needs should be regarded as factors affecting pedestrians' behavioral intention to share space and interact with AVs. Given that decision-making, such as AVA, has cognitive and affective components (Dimoka et al., 2007), prior research has proposed that cognitive and affective factors are critical to facilitate AVA (see Straub, 2009). Cognitive factors capture aspects that

Table 1
Overview of items in questionnaire.

Needs	Items (pre-/post- question code)	Original items/findings	Wording adjusted?	References
Safety	If the other vehicles around me were automated, I would reach my destination more safely (A101_01/A201_01)	Using a conditionally automated car would help me reach my destination more safely	Yes	Nordhoff et al. (2020)
	If the other vehicles around me were automated, I would feel safer (A101_02/A201_02)	I would feel safe to cross roads in front of FAVs	Yes	Deb et al. (2017)
	I would feel safer crossing the street in front of automated vehicles than crossing the street in front of vehicles driven by a human (A101_03/201_03)	I would feel safe to cross roads in front of FAVs	Yes	Deb et al. (2017)
Trust	I would trust the automated vehicle (A102_01/A202_01)	I can trust the automated vehicle	Yes	Choi & Ji (2015)
	I would let the automated vehicle pass before crossing the street in front of it (A102_03/A202_04) (reverse-coded)	Road users wait and let AV pass before moving	–	Self-developed, based on interview study (Nordhoff et al., 2025)
	I think that if I saw automated vehicles on the street, I would turn around and change the direction of travel (A102_04/A202_04) (reverse-coded)	Road users change direction of travel when being around AVs	–	Self-developed, based on interview study (Nordhoff et al., 2025)
	If the other vehicles around me were automated, I would become a more alert pedestrian (A102_05/A202_05) (reverse-coded)	Use of Tesla Autopilot by drivers contributes to increase in situational awareness	–	Self-developed, based on interview study (Nordhoff et al., 2023)
	I wouldn't pay attention to the automated vehicles around me as a pedestrian (A102_06/A202_06)	Use of Tesla Autopilot by drivers contributes to complacency	–	Self-developed, based on interview study (Nordhoff et al., 2023)
	I would intentionally step onto the road in front of an automated vehicle (A102_07/A102_07)	Road users intentionally step onto the road in front of AVs	–	Self-developed, based on interview study (Nordhoff et al., 2025)
	The automated vehicle would be reliable (A102_08/A202_08)	The automated vehicle is reliable	Yes	Choi & Ji (2015)
	I would feel comfortable if my loved ones crossed the street in front of an automated vehicle (A102_09/A202_09)	I would feel comfortable if my child, spouse, parents – or other loved ones – cross roads in the presence of FAVs	Yes	Deb et al. (2017)
	I would be afraid that the automated vehicle would make decisions that I cannot change (A102_10/A202_10) (reverse-coded)	–	–	Self-developed
	I would give way to the automated vehicle if I could (A103_06/A203_06) (reverse-coded)	Road users wait and let AV pass before moving	–	Self-developed, based on interview study (Nordhoff et al., 2025)
Pedestrian detection by AV	I expect the automated vehicle to stop when I want to cross the street in front of it (A102_02/A202_02)	Road users expect that AV will stop when they want to cross the road in front of the AV	–	Self-developed, based on interview study (Nordhoff et al., 2025)
	I expect the automated vehicle to correctly recognize me on the road (or be aware of my presence) (A102_11/A202_11)	Road users want to be acknowledged, recognized, or detected by the AV	–	Self-developed, based on interview study (Nordhoff et al., 2025)
Performance expectancy	If the other vehicles around me were automated, I would become a better road user as a pedestrian (A103_01/A203_01)	–	–	Self-developed
	It would be more useful to share the road with automated vehicles rather than with vehicles driven by a human (A103_02/A203_02)	I assume that a conditionally automated car would be useful in my daily life	Yes	Nordhoff et al. (2020)
	If the other vehicles around me were automated, it would be easier to reach my destination (A106_04/206_04)	I expect that a conditionally automated car would be easy to use	Yes	Nordhoff et al. (2020)
	If the other vehicles around me were automated, I would be able to complete my daily commute as a pedestrian faster (A103_04/A203_04)	Using a conditionally automated car would help me to reach my destination faster	Yes	Nordhoff et al. (2025)
	An automated vehicle would be more environmentally-friendly than a conventional vehicle (A103_05/A203_05)	–	–	Self-developed
Comfort and hedonic motivation	If the other vehicles around me were automated, I could travel more comfortably as a pedestrian (A104_01/A204_01)	Using a conditionally automated car would help me reach my destination more comfortably	Yes	Nordhoff et al. (2020)

(*continued on next page*)

Table 1 (*continued*)

Needs	Items (pre-/post- question code)	Original items/findings	Wording adjusted?	References
	If the other vehicles around me were automated, I would be able to travel more enjoyable as a pedestrian (A104_02/A204_02)	Using a conditionally automated car would be enjoyable	Yes	Nordhoff et al. (2020)
	If the other vehicles around me were automated, I would feel more comfortable as a pedestrian when I was tired or otherwise impaired (A104_03/A204_03)	I would feel more comfortable doing other things (e.g., checking emails on my smartphone, talking to my companions) while crossing the road in front of FAVs than non-automated cars	Yes	Deb et al. (2017)
	If the other vehicles around me were automated, I would feel more comfortable as a pedestrian in adverse weather conditions (e.g. heavy rain, fog, snow) (A104_04/A204_04)	I plan to use a conditionally automated car in adverse weather conditions such as during heavy rain or fog, and in darkness	Yes	Nordhoff et al. (2020)
Social influence	People in my immediate area would think it would be good to share the road with automated vehicles in the future (A105_01/ A205_01)	People who are important to me and/or influence my behavior trust FAVs (or have a positive attitude toward FAVs)	Yes	Deb et al. (2017)
	People in my immediate circle would think it would be good if in the future I no longer had to share the road with vehicles that are driven by a human, but are automated (A105_02/ A205_02)	People who are important to me would not think that I should cross roads in front of FAVs	Yes	Deb et al. (2017)
	People I care about would think I should share the road with automated vehicles (A105_03/ A205_03)	People who influence my behavior would think that I should cross roads in front of FAVs	Yes	Deb et al. (2017)
Well-being/ mental health	If the other vehicles around me were automated, I would have better awareness of my surroundings (e.g. other vehicles in adjacent lanes, road markings) (A106_01/ A206_01) (reverse-coded)	Use of Tesla Autopilot by drivers contributes to increase in situational awareness	–	Self-developed, based on findings from interview study (Nordhoff et al., 2023)
	If the other vehicles around me were automated, it would be more stressful to travel as a pedestrian (A106_02/A206_01) (reverse-coded)	Use of Tesla FSD by drivers makes driving more stressful	–	Self-developed, based on findings from interview study (Nordhoff et al., 2023)
	If the other vehicles around me were automated, it would be more relaxing to travel as a pedestrian (106_03/206_03)	Use of Tesla Autopilot by drivers makes driving more relaxing	–	Self-developed, based on findings from interview study (Nordhoff et al., 2023)
	If the other vehicles around me were automated, it would be more effortless as a pedestrian to reach my destination (A106_04/ A206_04)	I expect that a conditionally automated car would be easy to use	Yes	Deb et al. (2017)
	If the other vehicles around me were automated, I would be less aggressive towards other road users (A106_05/A206_05)	Use of Tesla Autopilot by drivers contributes to reduction in aggression towards other road users	–	Self-developed, based on findings from interview study (Nordhoff et al., 2023)
Behavioral intention	I plan to share the road with automated vehicles in the future (A107_01/A207_01)	I plan to buy a conditionally automated car once it is available	Yes	Nordhoff et al. (2020)
	I intend to share the road with automated vehicles in the future (A107_02/A207_02)	I intend to use a conditionally automated car in the future	Yes	Nordhoff et al. (2020)
	If the other vehicles around me were automated, I would travel less a pedestrian (A107_03/A207_03) (reverse-coded)	I would travel more in my daily life if travelling were easier	Yes	Lehtonen et al. (2022)

respondents evaluate as a result of logical reasoning and rational thinking, whereas affective constructs capture respondents' emotional responses to these aspects (Brase, 2019; Ferreira et al., 2014). Safety has both a cognitive and affective component, performance expectancy and trust are cognitive factors, and social influence, comfort, pleasure and mental health/well-being are affective factors. In contrast to Maslow's (1943) theory, our framework focuses on psychological needs, omitting the physiological needs as we believe they are not directly applicable to the AV-pedestrian context. Moreover, we do not explicitly identify the need for communication as unique need of pedestrians, but instead assume that this need is embedded across all layers of the pyramid. In driverless AVs, pedestrians can no longer rely on explicit communication due to the absence of a human driver (Kaye et al., 2022). Explicit communication refers to the communication via eye contact or gestures, whereas implicit communication refers to the communication via vehicle movements or dynamics (Harkin et al., 2023).

The needs in this framework are operationalized by questions that form our Automated Vehicle Acceptance Questionnaire for Pedestrians (AVAQ-P). Pedestrians should be treated as distinct road user group that differs from other (vulnerable) road user groups in their behaviors and needs (see Berge et al., 2023). While pedestrians, for example, mostly interact with vehicles at crossings, cyclists travel parallel to vehicles, experiencing passing, merging, and overtaking situations (Berge et al., 2024). For this reason, we develop a

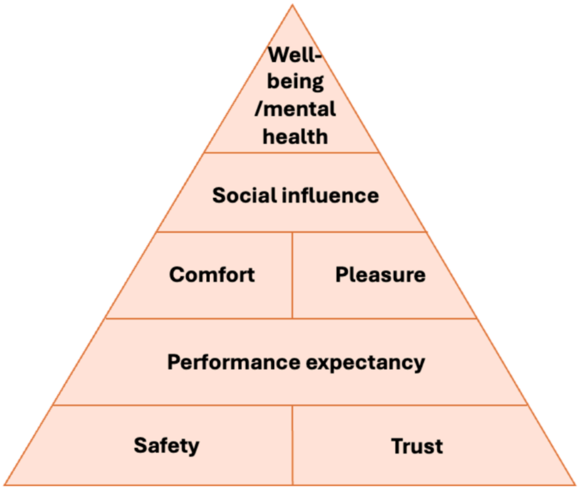

Fig. 1. Hierarchy of human needs in the AV context, proposed conceptual framework for the measurement of human needs in the AV context.

questionnaire specifically for pedestrians.

1.1. The present study

Most of the research examining AVA has examined the acceptance of AVs by drivers or passengers. However, vulnerable road users, such as pedestrians, will have to share space and interact with AVs on public roads. Understanding the factors impacting their acceptance is pivotal to ensure a large-scale and wide AVA. The main objective of this study is to examine the factors impacting the AVA by pedestrians, contributing to the development and validation of the automated vehicle acceptance questionnaire for pedestrians, i.e., the AVAQ-P. We adopted a four-step approach to develop and validate the questionnaire.

The subsequent sections provide an overview of the literature reviewed to identify, conceptualize and operationalize the needs of pedestrians in AV interactions. This section only reports the factors that are relevant for the context of the present study. Section 3 presents the methodology, Section 4 summarizes the results of this study, Section 5 discusses the results and mentions the study's limitations as well as avenues for future research.

2. Literature review

The present section reviews the empirical AVA literature to identify the needs of pedestrians sharing space and interacting with AVs. As shown by Fig. 1, we propose that the needs at the bottom of the pyramid are safety and trust. Safety captures the expected safety benefits associated with sharing space and interacting with AVs. The expected safety benefits that are associated with the introduction of AVs are typically measured by the reduction of the frequency and severity of road fatalities and injuries (Wang, Xie, Huang, & Liu, 2021; Yang & Fisher, 2021). Safety also includes an affective component –perceived safety – which refers to the extent to which individuals feel safe around AVs. The need for safety is supported by the empirical literature, which has shown that pedestrians were positive about AVs because the behavior of AVs was considered safer than the behavior of human drivers. Positive safety benefits pertained to AVs offering more space than human drivers, driving slower, and being better at detecting pedestrians. However, in the same study respondents also mentioned to feel unsafe around AVs because AVs behaved in disruptive and unexpected ways and failed to detect pedestrians (Nordhoff et al., 2025). Moreover, respondents with lower safety perceptions had more negative perceptions than respondents with higher AV safety perceptions (Rahman et al., 2021). In the study of De Miguel, Fuchshuber, Hussein, and Olaverri-Monreal (2019), participants mentioned that an image with information on the AV that acknowledged their presence as pedestrians would enhance their perceived safety.

Trust is defined as the "attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (Lee & See, 2004, p. 51). Trust is represented by the bottom layer of the pyramid. Trust can exceed (i.e., overtrust), or do not pass a certain threshold (i.e., distrust). Too little trust can reduce pedestrians' crossing intentions and their acceptance of AVs. Overtrust can promote misuse of AVs (Parasuraman & Riley, 1997). Misuse is defined as an inappropriate reliance on the capabilities of the automation (Lee, Liu, Domeyer, & DinparastDjadid, 2021), impacting user's decision to become complacent with the automation (Parasuraman & Riley, 1997). Pedestrians' expectation that AVs will stop or slow down can negatively impact traffic safety and efficiency (Deb et al., 2017; Prédhumeau et al., 2021; Rodríguez Palmeiro et al., 2018). In our recent study (Nordhoff et al., 2025) conducted with pedestrians interacting with driverless AVs in dedicated cities in the U.S., pedestrians took advantage of the capabilities of AVs, engaging in risky crossing maneuvers in front of AVs, which was associated with having too much trust in the capabilities of the AV to adequately detect and respond to them (overtrust).

The perceived benefits of AVs, which – in the technology acceptance management literature – are often conceptualized as perceived usefulness or performance expectancy, were strong drivers influencing attitudes and acceptance of drivers and passengers (Nastjuk, Herrenkind, Marrone, Brendel, & Kolbe, 2020). For this reason, the second layer at the bottom of the pyramid is represented by performance expectancy. Performance expectancy is generally defined as the degree to which the individual believes that using the system will support them in achieving gains in the performance of the task (Venkatesh, Morris, Davis, & Davis, 2003). Pedestrians highlighted several positive aspects of AVs' adherence to traffic rules, including making complete stops at stop signs, stopping behind lane markings, and driving within lanes and speed limits (Rahman et al., 2021). While the expected safety benefits resulting from the deployment of AVs can also be captured by performance expectancy (e.g., "Crossing roads in front of fully AVs would enable me to react to unsafe walking conditions more quickly") (Kaye et al., 2022, p. 7), our paper treats safety and performance expectancy as two separate needs. This decision is motivated by the dominant role of (perceived) safety for the acceptance of AVs, which is considered the most significant benefit of AVs (Nair & Bhat, 2021).

Previous studies on AVA identified comfort as influential factor influencing AVA (Peng et al., 2023). Comfort is defined as "the subjective feeling of pleasantness of driving / riding in a vehicle in the absence of both physiological and psychological stress" (Carsten & Martens, 2019, p.12). Comfort and pleasure represent the third-lowest layer of the pyramid. This layer captures the degree to which sharing space and interacting with AVs is considered comfortable from the perspective of pedestrians. The empirical literature on AVA has shown that pedestrians revealed some form of discomfort around AVs as they were not able to predict their behaviors while sharing the roads, which was associated with insufficient knowledge about, and an awareness of the limitations of the technology (Rahman et al., 2021). The review study of Prédhumeau, Spalanzani, and Dugdale (2021) has shown that participants felt some discomfort if the AV did not follow social norms. The authors posit that AVs should exhibit capabilities and features that mimic social behaviors or represent a functional substitute for human behavioral cues to enable acceptance (see Prédhumeau et al., 2021, p. 449).

In the technology acceptance literature, including the literature on AVA, hedonic components, such as feelings or pleasure (see Holbrock & Hirschman, 1982; Ross, 1979), are typically indicated by the construct hedonic motivation. Hedonic motivation captures the fun or pleasure derived from technology usage (Brown & Venkatesh, 2005). Prior studies identified hedonic motivation as a strong predictor of driver's behavioral intentions to use electric vehicles and AVs (Chaturvedi, Kulshreshtha, Tripathi, & Agnihotri, 2023; Nordhoff et al., 2020). Papadimitriou, Lassarre, and Yannis (2016) developed a questionnaire for pedestrians' crossing decisions, including the 'pedestrian for pleasure' component, which was measured by questionnaire items, such as 'walking for pleasure', or 'because it is healthy'. Deb et al. (2017, p. 183) also included this aspect in their questionnaire ("I would find it pleasant to cross the road in front of fully automated vehicles"). We position comfort and hedonic motivation on the same layer as it might be difficult for respondents to clearly discriminate between comfort and hedonic motivation when exposed to them in a questionnaire study given the similarity in their semantic meaning. Therefore, we do not expect that items measuring comfort and hedonic motivation represent two uni-dimensional constructs in our study.

Social influence refers to an individual's belief that people important to them think that the person should perform the behavior (Venkatesh & Morris, 2000). Social influence is represented by the second layer at the top of the pyramid. Social influence or subjective norms was included in technology acceptance models (i.e., Theory of Planned Behavior, TPB, Ajzen (1991); Unified Theory of Acceptance and Use of Technology, UTAUT, Venkatesh, Thong, & Xu (2012)) as determinant affecting the intention to use information technology. Prior studies mostly examined the effect of social influence on the behavioral intention to use AVs from the perspective of drivers and passengers of AVs. Little is known about how social influence affects the intention to use AVs from the perspective of pedestrians. Kaye et al. (2022) found that subjective norm influenced pedestrians' crossing decisions in front of AVs, supporting previous research (Li et al., 2023). In the AV-pedestrian context, social influence is also expressed by surrounding pedestrians or other road users mimicking behavior, such as crossing the road, waiting in front of a crosswalk, or hesitating before crossing the road (Prédhumeau et al., 2021).

Well-being captures an individual's mental health, which allows them to realize their own abilities, coping with the normal stresses of life, working productively and fruitfully, and contributing to their community (WHO, 2004). It is represented by the top of the pyramid. The promotion of mental health, prevention and treatment of mental disorders is one of the top health challenges considered fundamental to securing and enhancing the quality of life, well-being, and the productivity and thus resilience of society (WHO, 2015). Given this importance, it is not surprising that the topic of mental health has received attention from various domains, such as artificial intelligence (Al-Azzawi, 2021), public policy (Sachs, 2019), consumption (Reimann, MacInnis, & Bechara, 2016), and transportation (Conceição et al., 2023; Koch et al., 2021; Posner, Durrell, Chowdhury, & Sharp, 2018). The relationship between mental health and the use of AVs by pedestrians has received scant attention so far. Mental health can be measured on a spectrum, ranging from affective states (i.e., emotions and mood), well-being and satisfaction with life or travel, to mental health disorders. Moods are typically understood as more diffuse, and longer-lasting affective states in comparison to more specific and shorter termed emotions. Moods are usually measured on a full spectrum using instruments such as the Global Mood Scale – GMS, or the Brief Mood Introspection Scale – BMIS (Conceição et al., 2023). Studies examining human emotion recognition in the automotive domain have typically measured drivers' high arousal emotional states, such as anger, stress, happiness, and sadness (Zepf, Hernandez, Schmitt, Minker, & Picard, 2020). In the context of AV-pedestrian interaction, studies have shown that pedestrians experienced stress, nervousness, fear, anxiety or surprise when encountering an AV (Habibovic et al., 2018; Nordhoff et al., 2025). Prédhumeau et al. (2021) expected pedestrians to get angry in situations in which the AV does not recognize or give priority to them, which supports research which has revealed an increase in anger and frustration of road users interacting with AVs (Nordhoff et al., 2025).

2.1. Individual characteristics

Individual characteristics of pedestrians, such as their demographics and affinity for technology interaction, influenced pedestrians' crossing decisions in front of AVs and their AVA. The literature reveals that the effect of demographic characteristics, such as age and gender, on crossing behavior and AVA by pedestrians are mixed. The effect of age had a small negative effect on pedestrians' crossing intentions, suggesting that elderly people were less likely to cross the road in front of AVs. Gender did not affect pedestrian's crossing intentions in the study of Kaye et al. (2022), while male pedestrians accepted shorter gap distances between them and AVs in the study of Rodríguez Palmeiro et al. (2018). In Deb et al. (2017), respondents aged between 18–30 years reported a higher willingness to cross the road in front of AVs than respondents aged $\geq$ 31. Males were more likely to feel safe around AVs than females, considering it easier to interact with AVs at crosswalks compared to females, while the effect of age was not significant. Age and gender did not correlate with pedestrians' trust in AVs (Rodríguez Palmeiro et al., 2018), supporting research which has shown that the perception of pedestrians towards AVs (i.e., positive, negative, mixed) did not vary across different age groups (Rahman et al., 2021).

The inclusion of age and gender as moderator variables in models that explain the AVA by pedestrians is limited. A moderator variable is a third variable that affects the strength or direction of a relationship between two variables (Sarstedt et al., 2020). Venkatesh et al. (2003) found that the effect of performance expectancy on behavioral intention was moderated by gender and age, with their effect of being stronger for men and younger respondents. Moreover, the effect of social influence on behavioral intention was stronger for women, respondents who were older and who had limited experience with the technology. In the study of Park, Hong, and Le (2021), age moderated the relationships between perceived usefulness (an equivalent to performance expectancy), social influence, and behavioral intention to use AVs, respectively. In Hőgye-Nagy, Kovács, and Kurucz (2023), gender moderated the relationship between attitudes towards AVs, reflecting the perceived benefits and concerns associated with AV deployment, and AVA. We could not identify any other study that included age and gender as moderators in models explaining the AVA by pedestrians. To address this knowledge gap, we hypothesize that the relationships between the latent variables in our model are moderated by age and gender. We also estimate the direct effects of age and gender on the latent variables in our model, based on previous technology acceptance research (Venkatesh et al., 2003).

Despite its critical importance, little is known about the role of pedestrian's personality on their interactions with AVs. One personality dimension is the affinity for technology interaction, which refers to the extent to which individuals actively approach or avoid the interaction with new systems (Franke et al., 2019). Technology affinity, which is conceptually similar to the affinity for technology interaction, had a positive effect on trust in AVs, suggesting that individuals with higher levels of technology affinity are more likely to trust AVs (Mosaferchi et al., 2023). In another study, technology affinity had a positive effect on the preferred level of vehicle automation (Öztürk et al., 2024). A related construct is technology readiness, which has been identified as a factor that promotes or hinders the adoption of new technologies (Liljander et al., 2006). It refers to the propensity of an individual to embrace and use new technologies to accomplish goals in their home life and at work (Parasuraman, 2000). It has been shown that a higher technology readiness was associated with more positive views towards AVs and a higher intention to use AVs (O'Hern & St. Louis, 2023). In Deb et al. (2017), personal innovativeness had a positive effect on safety and interaction, suggesting that pedestrians scoring high on this dimension were more likely to feel safe around AVs, and when crossing the road in front of AVs.

2.2. Hypothesis development

Based on the results of the literature review, the present study derives the following nine testable hypotheses.

H1: If pedestrians appreciate the safety benefits of AVs compared to human-controlled cars and feel safe around them, they are more likely to intend to share space with them.
H2: If pedestrians trust AVs, they are more likely to intend to share space with them.
H3: If pedestrians consider sharing space with AVs efficient, they are more likely to intend to share space with them.
H4: If pedestrians consider sharing space with AVs comfortable, they are more likely to intend to share space with them.
H5: If pedestrians consider sharing space with AVs pleasurable, they are more likely to intend to share space with them.
H6: If important people in the pedestrians' social networks support the pedestrians' acceptance of AVs, they are more likely to intend to share space with them.
H7: If pedestrians expect a positive impact on their well-being / happiness as a result of sharing space with AVs, they are more likely to intend to share space with them.
H8: Pedestrians with a higher affinity for technology interaction will be more likely to intend to share space with AVs than pedestrians with a lower affinity for technology interaction.
H9: Age and gender will moderate the relationships between performance expectancy, social influence, and behavioral intention, such as that the relationships will be stronger for young males.

3. Methodology

3.1. Experimental procedure

An online questionnaire was developed in the Hi-Drive project (https://www.hi-drive.eu/), and data collection was performed among German residents between August and October 2023. The questionnaire included a pre-and post-AV exposure component by showing respondents a video displaying an AV equipped with a light band in a shared space environment, which will be described in greater detail in Section 3.2.

The implementation of the questionnaire was conducted by the Institute of Transportation Systems of the German Aerospace Center

(DLR) using the SoSci Survey tool (https://www.soscisurvey.de).

The questions were translated from English into German by the authors of the present study. The translation was conducted in three main steps. First, the corresponding researcher of the present study used the translation service 'Google Translate' (Google Translate) to translate the items from English to German. Second, the researcher checked the results of Google Translate, and performed adjustments when needed. Third, the researcher discussed these items with the other co-authors, which resulted in further revisions until the researchers agreed on a final set of items. Table A1 in the appendix provides the final list of questionnaire items that were presented to respondents in the survey. Respondents were invited to participate in the study via email and social media platforms, such as LinkedIn and platforms of the Technical University Berlin in Germany (e.g., https://tu-berlin.sona-systems.com/Default.aspx?ReturnUrl=%2f).

To compensate respondents for participation in the questionnaire, respondents were able to participate in a lottery. A total of four vouchers from the company "Wunschgutschein" (https://www.wunschgutschein.de/), each worth of 25€ (totaling 100 €) were raffled among respondents. At the end of the questionnaire, respondents were asked to indicate their willingness to participate in the raffle. Those who wished to participate provided their email addresses. The winners were selected by generating four random numbers among all participants. The winners were then contacted via email, and the vouchers were sent to them online.

Ethical approval for the study was obtained from the German Aerospace Ethical Board (ID: 22/24).

3.2. Questionnaire content

The questionnaire was divided into several sections.

First, respondents were informed about the nature and purpose of the study, and that their data would be treated anonymously. They were informed that they will watch videos in which they interacted with a fully automated vehicle as pedestrian in a shared space area, which is why they were instructed to not perform the study on their smartphones. The instructions also provided a definition of a shared space area. A shared space area was defined as a traffic-calmed space in which all road users have equal rights. In shared space areas, the traffic rule 'right before left' and driving at an appropriate speed apply to ensure the mutual consideration of all road users.

Second, respondents were asked to answer the acceptance questions that we presented in Table 1.

Third, participants were asked to view five training videos with a length of approximately nine seconds. The training videos presented the traffic situation and visual cues as shown in the experimental videos that respondents were asked to view in step 4. This was done to help respondents understand the experimental videos. The visual cues in the training videos include a shared space environment (video 1), an AV approaching (video 2), a pedestrian approaching (video 3), an AV with a static light band (indicating automated mode) approaching (video 4), and an AV with a pulsing light band (signaling the AV's intention to yield) approaching (video 5).

The shared space environment was selected because it represents a complex and increasingly common traffic environment where pedestrians and AVs must interact without the guidance of strict traffic rules or signals. A crossing situation was chosen as it represents the most common AV-pedestrian interaction scenario and safety–critical situation (Gronier et al., 2024; Hübner et al., 2025; Zou et al., 2023). A light band as external form of communication was selected because prior research has shown that light bands impact pedestrians' perceived safety, trust and willingness to cross in front of AVs (Colley et al., 2022; Werner, 2018). The light band was designed as an external Human-Machine-Interface (eHMI) to communicate the AV's behavior and intentions explicitly to pedestrians and other road users. The light band used in our study was a 360° LED strip mounted around the chassis of the AV. It was colored in Cyan in its static state to indicate the vehicle's automation status. When the AV intended to yield, the light band changed to a pulsing state (0.5 Hz), signaling this intention explicitly. This design choice was informed by previous research suggesting that Cyan is a highly visible and neutral color in traffic contexts, making it suitable for eHMI applications (see Werner, 2018). We informed respondents that the light band would light up continuously, signaling that the vehicle is operating in fully automated mode, that the vehicle and pedestrian may or may not stop, and that the AV communicates by the light band. Moreover, respondents were informed that the videos would be played without tone.

Fourth, participants viewed 12 experimental videos. Each of these videos lasted approximately 10 s. The experimental videos systematically varied the visual cues shown in the training videos using a $3 \times 2 \times 2$ within-subjects design. The first factor captured pedestrian behavior (i.e., absent, yielding, or walking), the second was vehicle kinematics (i.e., yielding vs. non-yielding), and the third was eHMI status (i.e., no eHMI vs. active eHMI). Participants, from a pedestrian's first-person perspective, were asked to cross the space in front of an approaching AV. Depending on the condition, an additional pedestrian was either present or absent. After one second, the view panned to the right (simulating a slight head turn) revealing the AV approaching from the distance at a constant speed of approximately 30 km/h. In the final camera position, both the additional pedestrian and the AV were visible, allowing participants to observe the full interaction scenario. The video faded to black at a distance of 11 m between the AV and the participant's position (before the AV came to a complete stop) to ensure that participants had sufficient time to view the situation without witnessing the final vehicle reaction. After each video, they responded to three questions assessing their willingness to cross on a scale from 1 = very unwilling to 7 = very willing, perceived safety while crossing on a scale from 1 = very unsafe to 7 = very safe, and the extent to which the movements of the AV and the pedestrian informed their crossing decision on a scale from little (1) to strong (7). Unlike the experimental videos, the training videos were not subjected to the analysis.

These questions were designed to assess how the combinations of eHMI, AV behavior, and additional pedestrian behavior influenced participants' responses to the three questions in each scenario. The analysis of this data will not be presented in this paper.

Fifth, respondents were asked to complete the acceptance questions again (see Table 1).

In the final part of the questionnaire, respondents were asked to provide personal information, such as their gender, age, and access to a valid driver's license. Moreover, they were asked to indicate whether they have heard of AVs before, and if so, how (i.e., newspapers, radio, TV, internet, personal stories, own experience, other). Next, respondents were asked to rate their affinity for technology interaction using the scale from Franke, Attig, and Wessel (2019) on a scale from strongly disagree (1) to strongly agree (7). Then they were presented with questions measuring their ability to watch the vehicle and the light band located on the vehicle, changes in the light band, vehicle, and pedestrian, using a scale from Yes (1), No (2), to I don't know (3). Finally, they were asked to indicate to what extent they replied to the questions with care, using a scale from carelessly (1) to careful (7).

3.3. Questionnaire development and validation

The questionnaire was developed in four main stages, as presented below and visualized in Fig. 2, following the recommendations for questionnaire development and validation outlined in Hair et al. (2019).

In the first stage, which we call ideation stage, we reviewed the empirical literature on AVs and Maslow's hierarchy of needs (Maslow & Lewis, 1987) to identify the needs of pedestrians sharing space with AVs.

In the second stage – the theoretical validation of the questionnaire – we translated the needs into measurable, operational questionnaire items to ensure the assessment of AVA by pedestrians in a standardized way over time. We followed deductive and inductive scale principles for the development of the questions in line with Hinkin (1998). To ensure content validity, we utilized existing questions or made slight adjustments to them when a strong theoretical foundation provided sufficient information to guide item development. We developed questions inductively by reviewing the literature, particularly in areas where there was limited knowledge about certain aspects of pedestrian-AV interactions. The content and face validity of the questionnaire items were subjectively assessed in discussions between the researchers of the study. Content validity refers to the extent to which an instrument captures a specified content domain comprehensively and in a representative way (Yaghmaie, 2003). Face validity is defined as the extent to which a measure (i.e., questionnaire item), at the surface, appropriately represents the underlying theoretical construct it is supposed to measure (Bagby, Goldbloom, & Schulte, 2006). We also inspected the means and standard deviations of the questions to assess whether they are in the expected range and correspond with the means and standard deviations of the other items representing the same underlying construct. A Paired sample t-Test was conducted to determine whether the differences in the mean ratings before and after AV exposure were statistically different. We discussed the appropriateness of the item wording and considered whether certain items should be removed or included in the scale. Furthermore, we examined whether any terms used in the items might be misunderstood by respondents. We also assessed whether each group of items effectively represents their underlying latent construct related to pedestrians' needs when sharing space with AVs (Hair, LDS Gabriel, Silva, & Braga, 2019). Each need is represented by at least three items in line with general recommendations for questionnaire development (Lambert & Newman, 2023).

In the third step — semantic validation of the questionnaire — we distributed the questionnaire to approximately 20 experts affiliated with the organizations of the participating researchers. This step aimed to evaluate the questionnaire's effectiveness and identify any difficulties the experts encountered in understanding the semantics of the items. Based on their feedback, we made further

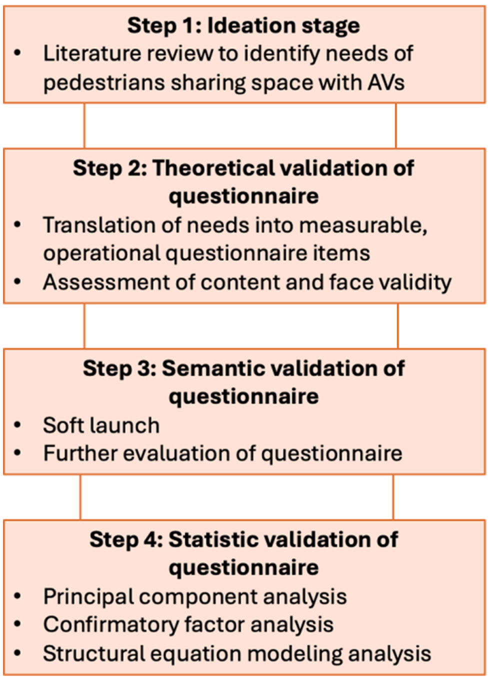

Fig. 2. Methodology for questionnaire development and validation

adjustments to the wording of the questions to enhance clarity and comprehension (see Hair et al., 2019).

In the fourth step, we proceeded with the statistical validation of the questionnaire. This step involves the analysis of the data, which was conducted in three steps following the procedure for questionnaire validation as mentioned in Bothelius et al. (2015).

First, to reduce questionnaire complexity, a principal component analysis (PCA) was conducted to explore the underlying factor structure (Hair et al., 2019) as several questions were self-developed. The PCA was performed using varimax rotation as the most used rotation method (Hair et al., 2019). To estimate the number of components, a scree plot analysis was performed, selecting the principal components with an Eigenvalue above 1 (Hair et al., 2019). The PCA was performed stepwise, omitting items with principal component loadings of ≤ 0.40 from the analysis in line with Peterson (2000), and then redoing the analysis with the remaining number of items. Items with cross-loadings were inspected, and assigned to the most suitable principal component based on theoretical reasoning and the empirical literature, or they were removed.

Second, a confirmatory factor analysis was performed to estimate the measurement relations between the latent constructs and underlying questionnaire items. For this reason, internal consistency reliability (i.e., Cronbach's alpha, composite reliability), discriminant validity, and convergent validity were assessed. Discriminant validity refers to the degree to which a latent construct is uni-dimensional and thus empirically distinct from the other latent constructs in the model both in terms of its correlation with other constructs and in terms of the correlations between each observed variable (i.e., questionnaire item) and the underlying latent construct (Sarstedt et al., 2014).

To assess convergent validity, the factor loadings (i.e., lambdas) should be significant, exceeding the threshold of 0.70 on their respective scales. The Average Variance Extracted (AVE) should exceed the threshold of 0.50, and the construct reliability (CR), and Cronbach's alpha values should be higher than 0.60. Discriminant validity (i.e., uni-dimensionality) of the latent constructs is established if the square root of the AVE of each latent construct exceeds the correlation coefficients between the latent constructs (Anderson & Gerbing, 1988; Hair, 2009). The fit of the measurement model is considered acceptable if the Comparative Fit Index (CFI) ≥ 0.95, Root Mean Square Error of Approximation) ≤ 0.08, and the Standardized Root Mean Square Residual (SRMR) ≤ 0.06 (Hair, 2009).

Third, a structural equation modeling analysis was run, which is based on the acceptable measurement model identified in the second step of the analysis. This involves testing the structural path relationships between the latent constructs in the model, examining the standardized regression coefficients, standard error terms, significance levels, and variance accounted for in the outcome variables. The analysis was conducted in R.

The questionnaire items are presented in Table 1, which provides an overview of how the questionnaire items were developed, supporting other researchers to replicate the process and ensure transparency (see Hair et al., 2019). The column 'Original items/findings' captures the original items or study findings that motivated the development of our questionnaire items. Column 'Wording adjusted?' refers to the extent to which the wording of our item was adjusted to better reflect the context of the present study.

The questions were asked on a seven-point Likert scale from strongly disagree (1) to strongly agree (7). The order of the questions was randomized to rule out order effects.

3.4. *Data filtering*

Strict data filtering was applied to increase data quality.

Participants with a relative speed index of ≥ 2.0 (i.e., completing the survey in less than half the median time) were flagged and excluded from the analysis to ensure data quality. The relative speed index indicates the time a respondent needs to complete the survey compared to the typical respondent (median). It is a metric to identify participants who completed the questionnaire at an unrealistically fast pace, potentially indicating a lack of diligence. It was calculated by comparing each participant's completion time to the median completion time across all participants (Leiner, 2019).

Moreover, we removed respondents who replied to the questions:

- „*How carefully did you answer the questions?*" with careless or rather careless;
- „*Were you able to see the vehicles clearly in the videos?*" with No;
- „*Were you able to clearly see the light strip on the vehicle in the videos?*" with No;
- „*Did you notice any changes to the vehicle behavior?*" with No; and
- „*Did you notice any changes to the light strip in the videos?*" with No.

4. Results

4.1. *Respondents*

In total, the questionnaire was completed by 155 respondents. After data filtering, 136 responses remained for the analysis. The mean age of respondents was 31.54 years (SD = 11.21, min = 19, max = 67), and 40 % of respondents were Male, and 60 % were Female. 98 % of respondents have heard of AVs before participation in the questionnaire compared to 2 % of respondents who have not heard about AVs before. The most dominant information source was the internet, with 81 % of respondents stating to receive information about AVs from the internet. 64 % of respondents received information about AVs from the TV, 46 % from personal stories, 37 % from newspapers, and 23 % from the radio. 24 % personally experienced AVs themselves, e.g., through a test ride.

4.2. Descriptive statistics

We examined the descriptive statistics of some acceptance questionnaire items distributed to respondents pre- and post-AV experience. The highest mean rating was obtained for expecting the AV to correctly recognize them on the road (or be aware of their presence) before and after AV-experience (***M*** = 5.83, SD = 1.39 and ***M*** = 5.51, SD = 1.57 respectively; t(135) = 3.32, $p < 0.001$). The second-highest mean rating was obtained for expecting the AV to stop when wanting to cross the road in front of it before and after AV experience (***M*** = 5.51, SD = 1.42 and ***M*** = 5.46, SD = 1.48 respectively; t(135) = 1.72, $p = 0.08$). The third-highest rating was found for planning to share the road with AVs in the future before (***M*** = 4.74, SD = 1.49), and after AV experience (***M*** = 4.74, SD = 1.49, and ***M*** = 4.76, SD = 1.49 respectively; t(135) = -0.32, $p = 0.74$).

The lowest mean rating was found for intentionally stepping on the road in front of an AV before and after AV experience (***M*** = 1.90, SD = 1.31 and ***M*** = 1.96, SD = 1.31 respectively; t(135) = -0.38, $p = 0.69$). The second lowest mean rating was obtained for giving way to the AV before and after AV experience (***M*** = 2.01, SD = 1.36 and ***M*** = 1.97, SD = 1.34 respectively; t(135) = -0.38, $p = 0.69$). The third-lowest mean rating was found for travelling less as pedestrian if the other vehicles were automated before and after AV experience (***M*** = 2.43, SD = 1.43 and ***M*** = 2.65, SD = 1.48 respectively; t(135) = -0.38, $p = 0.07$).

4.3. Principal component analysis

The Kaiser-Meyer-Olkin (KMO) measure of Sampling Adequacy is 0.84, exceeding the required threshold of 0.80, which suggests that the data is suitable for running a principal component analysis (Hair, 2009). Based on the analysis of the scree plot and the Eigenvalues of the principal components (PCs) > 1, as presented by Fig. 3, we extracted a seven-factor solution.

We performed a PCA with 44 items and inspected the composition of the principal components. We maintained items with factor loadings of ≥ 0.50, and removed items with cross-loadings following practical guidelines for conducting a PCA in Hair et al. (2019). We removed items with loadings of < 0.50 on more than one principal component (i.e., cross-loadings), which led us to maintain a seven-factor structure consisting of 35 items, as presented in Table 2.

The first principal component represents items pertaining to the construct ‘performance expectancy’. The items with the highest loading were ‘If the other vehicles around me were automated, I would be able to travel more enjoyable as a pedestrian’, and ‘If the other vehicles around me were automated, I would be able to travel more easily as a pedestrian’ (0.83). The item with the lowest loading was ‘If the other vehicles around me were automated, I would become a better road user as a pedestrian’ (0.54). The composition of PC1 reflects the content of other performance expectancy scales (e.g., Nordhoff et al., 2020).

The second principal component represents items reflecting the construct ‘affinity for technology interaction’ as used in Franke et al. (2019). The item with the highest loading was ‘I like to take a closer look at technical systems’ (0.91), while the item with the lowest loading was ‘First and foremost, I work with technical systems because I have to’ (0.67).

The third principal component captures questionnaire items capturing the expected attentiveness of pedestrians interacting with AVs. The item with the highest loading was ‘If the other vehicles around me were automated, I would become a more alert pedestrian’ (0.75), and the item with the lowest loading was ‘I would let the automated vehicle pass before crossing the street in front of it’ (0.44).

The fourth principal component captures respondents’ trust in AVs. The item with the highest loading was ‘I would intentionally step on the road in front of an automated vehicle’ (0.80), and the item with the lowest item was ‘I wouldn’t pay attention to the automated vehicles around me as a pedestrian’ (0.67).

The fifth principal component represents items measuring the construct ‘social influence’. The item ‘People in my immediate area would think it would be good to share the road with automated vehicles in the future’ had the highest loading (0.85), and the items ‘People I care about would think I should share the road with automated vehicles’ and ‘People in my immediate circle would think it would be good if in the future I no longer had to share the road with vehicles that are driven by a human, but are automated’ had the

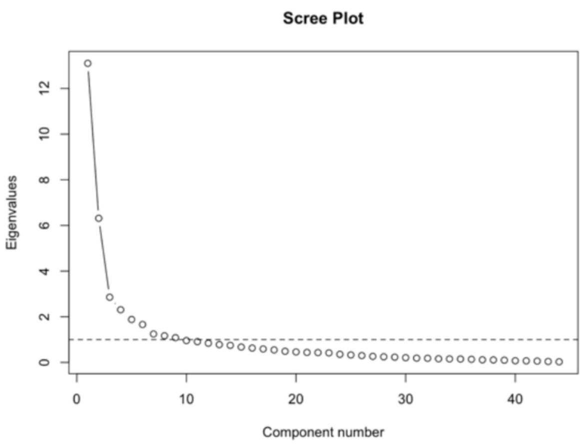

Fig. 3. Scree plot, pre-AV experience.

Table 2
Results of principal component analysis, pre-AV experience.

Questionnaire item	Principal components						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
A103_03: If the other vehicles around me were automated, I would be able to travel more easily as a pedestrian	0.83						
A104_02: If the other vehicles around me were automated, I would be able to travel more enjoyable as a pedestrian	0.83						
A106_04: If the other vehicles around me were automated, I would arrive less tired	0.81						
A106_03: If the other vehicles around me were automated, it would be more relaxing to travel as a pedestrian	0.80						
A104_01: If the other vehicles around me were automated, I could travel more comfortably as a pedestrian	0.80						
A101_02: If the other vehicles around me were automated, I would feel safer	0.80						
A101_01: If the other vehicles around me were automated, I would reach my destination more safely	0.80						
A104_03: If the other vehicles around me were automated, I would feel more comfortable as a pedestrian when I was tired or otherwise impaired	0.79						
A104_04: If the other vehicles around me were automated, I would feel more comfortable as a pedestrian in adverse weather conditions (e.g. heavy rain, fog, snow)	0.79						
A101_03: I would feel safer crossing the street in front of automated vehicles than crossing the street in front of vehicles driven by a human	0.78						
A103_04: If the other vehicles around me were automated, I would be able to complete my daily commute as a pedestrian faster	0.73						
A103_02: It would be more useful to share the road with automated vehicles rather than with vehicles driven by a human	0.67						
A106_05: If the other vehicles around me were automated, I would be less aggressive towards other road users	0.61						
A102_01: I would trust the automated vehicle	0.61						
A102_09: I would feel comfortable if my loved ones crossed the street in front of an automated vehicle	0.57						
A102_08: The automated vehicle would be reliable	0.55						
A103_01: If the other vehicles around me were automated, I would become a better road user as a pedestrian	0.54						
AT01_01: I like to take a closer look at technical systems		0.91					
AT01_04: Whenever I have a new technical system in front of me, I try it out intensively		0.90					
AT01_05: I really enjoy spending time getting to know a new technical system		0.89					
AT01_02: I like trying out the functions of new technical systems		0.89					
AT01_07: I'm trying to understand exactly how a technical system works		0.87					
AT01_06: It's enough for me that a technical system works, I don't care how or why		0.83					
AT01_09: I try to fully exploit the possibilities of a technical system		0.79					
AT01_08: It is enough for me to know the basic functions of a technical system		0.72					
AT01_03: First and foremost, I work with technical systems because I have to		0.67					
A102_05: If the other vehicles around me were automated, I would become a more alert pedestrian			0.75				
A106_01: If the other vehicles around me were automated, I would have better awareness of my surroundings (e.g. other vehicles in adjacent lanes, road markings)			0.67				
A102_07: I would intentionally step onto the road in front of an automated vehicle				0.80			
A103_06: I would give way to the automated vehicle if I could				0.72			
A102_06: I wouldn't pay attention to the automated vehicles around me as a pedestrian				0.67			
A105_01: People in my immediate area would think it would be good to share the road with automated vehicles in the future					0.85		
A105_03: People I care about would think I should share the road with automated vehicles					0.82		
A105_02: People in my immediate circle would think it would be good if in the future I no longer had to share the road with vehicles that are driven by a human, but are automated					0.82		
A102_11: I expect the automated vehicle to correctly recognize me on the road (or be aware of my presence)						0.84	
A102_02: I expect the automated vehicle to stop when I want to cross the street in front of it						0.82	
A107_01: I plan to share the road with automated vehicles in the future							0.60
A107_02: I intend to share the road with automated vehicles in the future							0.54

lowest (0.82). This component reflects the scale 'social influence' applied in Nordhoff et al. (2020).

The sixth principal component – AV-pedestrian detection – represents items that measure respondents' expectation of being detected by the AV, stopping for them in crossing situations. Two items loaded on PC6. These were 'I expect the automated vehicle to stop when I want to cross the street in front of it' (0.84), and 'I expect the automated vehicle to correctly recognize me on the road (or be aware of my presence) (0.82)'.

The seventh principal component represents items representing the construct 'behavioral intention'. The item with the highest loading was 'I plan to share the road with automated vehicles in the future' (0.60), and the item with the lowest loading was 'I plan to share the road with automated vehicles in the future' (0.54). This scale reflects the behavioral intention scale in studies on AVA (Nordhoff, De Winter, Kyriakidis, Van Arem, & Happee, 2018).

The variance accounted for by the first, second, third, fifth, fourth, sixth, and seventh principal component is 24 %, 16 %, 6 %, 6 %, 5 %, 5 %, and 5 %, respectively.

4.4. Confirmatory factor analysis

We subjected the seven principal components to a confirmatory factor analysis, which resulted in maintaining five latent variables with standardized factor loadings ƛ exceeding the recommended threshold of 0.70 and internal consistency (Cronbach's alpha, α) and composite reliability coefficients exceeding the minimum thresholds of 0.70 for all constructs pre-and post-AV experience. The average variance extracted (AVE) exceeded the recommended threshold of 0.50 for all latent constructs. The five factors are performance

Table 3
Confirmatory factor analysis results (ƛ = lambda, α = Cronbach's alpha, CR = Composite reliability, AVE = Average Variance Extracted, pre- and post-AV experience).

Latent variable	Observed variable (question codes)	Pre M (SD)	Post M (SD)	Pre ƛ	Post	Pre α	Post	Pre AVE	Post
PE	PE1: If the other vehicles around me were automated, I would be able to travel more enjoyable as a pedestrian (A104_02, A204_02)	4.01 (1.41)	3.83 (1.51)	0.88	0.90	0.95	0.97	0.66	0.75
	PE2: If the other vehicles around me were automated, I would feel more comfortable as a pedestrian when I was tired or otherwise impaired (A104_03, A204_03)	3.88 (1.49)	3.77 (1.63)	0.84	0.91				
	PE3: If the other vehicles around me were automated, I could travel more comfortably as a pedestrian (A104_01, A204_01)	3.74 (1.39)	3.75 (1.51)	0.82	0.90				
	PE4: If the other vehicles around me were automated, I would feel more comfortable as a pedestrian in adverse weather conditions (e.g. heavy rain, fog, snow) (A104_04, A204_04)	3.60 (1.63)	3.57 (1.67)	0.82	0.78				
	PE5: If the other vehicles around me were automated, it would be more relaxing to travel as a pedestrian (A106_03, A206_03)	3.88 (1.44)	3.78 (1.60)	0.82	0.87				
	PE6: If the other vehicles around me were automated, I would be able to travel more easily as a pedestrian (A103_03, A203_03)	3.62 (1.41)	3.76 (1.56)	0.79	0.87				
	PE7: If the other vehicles around me were automated, I would arrive less tired (A106_04, A206_04)	3.64 (1.40)	3.69 (1.51)	0.79	0.84				
	PE8: If the other vehicles around me were automated, I would reach my destination more safely (A101_01, A201_01)	4.08 (1.52)	4.16 (1.53)	0.79	0.80				
	PE9: If the other vehicles around me were automated, I would feel safer (A101_02, A201_02)	3.85 (1.61)	3.96 (1.51)	0.80	0.86				
	PE10: I would feel safer crossing the street in front of automated vehicles than crossing the street in front of vehicles driven by a human (A101_03, A201_03)	3.56 (1.48)	3.85 (1.65)	0.77	0.90				
SI	SI1: People I care about would think I should share the road with automated vehicles (A105_03, A205_03)	3.91 (1.31)	3.96 (1.37)	0.91	0.95	0.87	0.92	0.70	0.80
	SI2: People in my immediate area would think it would be good to share the road with automated vehicles in the future (A105_01, A205_01)	4.01 (1.37)	3.94 (1.36)	0.81	0.91				
	SI3: People in my immediate circle would think it would be good if in the future I no longer had to share the road with vehicles that are driven by a human, but are automated (A105_02, A205_02)	3.68 (1.29)	3.81 (1.38)	0.78	0.81				
APD	APD1: I expect the automated vehicle to correctly recognize me on the road (or be aware of my presence) (A102_11, A202_11)	5.83 (1.39)	5.51 (1.57)	1.01	1.00	0.79	0.74	0.71	0.67
	APD2: I expect the automated vehicle to stop when I want to cross the street in front of it (A102_02, A202_02)	5.51 (1.42)	4.29 (1.41)	0.64	0.59				
ATI	AT1: Whenever I have a new technical system in front of me, I try it out intensively (AT01_04)	3.93 (1.37)	3.93 (1.37)	0.93	0.93	0.95	0.95	0.74	0.74
	AT2: I really enjoy spending time getting to know a new technical system (AT01_05)	3.84 (1.43)	3.84 (1.43)	0.92	0.93				
	AT3: I like trying out the functions of new technical systems (AT01_02)	4.19 (1.38)	4.19 (1.38)	0.92	0.92				
	AT4: I like to take a closer look at technical systems (AT01_01)	4.05 (1.37)	4.05 (1.37)	0.92	0.92				
	AT5: I'm trying to understand exactly how a technical system works (AT01_07)	3.62 (1.49)	3.62 (1.49)	0.84	0.84				
	AT6: I try to fully exploit the possibilities of a technical system (AT01_09)	4.01 (1.36)	4.01 (1.36)	0.77	0.77				
	AT7: It's enough for me that a technical system works, I don't care how or why (AT01_06)	4.67 (1.54)	4.67 (1.54)	0.73	0.73				
BI	BI1: I intend to share the road with automated vehicles in the future (A107_02, A207_02)	4.70 (1.51)	4.74 (1.51)	0.98	0.98	0.98	0.98	0.95	0.96
	BI2: I plan to share the road with automated vehicles in the future (A107_01, A207_01)	4.74 (1.49)	4.76 (1.49)	0.97	0.98				
Model fit	CFI			0.89	0.89				
	RMSEA			0.10	0.10				
	SRMR			0.06	0.06				

expectancy, social influence, AV-pedestrian detection, affinity for technology interaction and behavioral intention. Items with loadings of ≤ 0.60 were removed from the confirmatory factor analysis (Table 3).

As shown by Table 4, the square root of the AVE of all constructs exceeded the correlation coefficients of the relationships between all constructs, demonstrating that the latent constructs are sufficiently distinct (discriminant validity).

4.5. Structural equation modeling results

In this section, we will present the results of the structural equation modeling analysis. Most of our hypotheses were supported, as shown by Table 5.

Performance expectancy had the strongest effect on pedestrians' behavioral intention to share space with AVs. This suggests that pedestrians will be more likely to intend to share space and interact with AVs if the interaction with AVs is more enjoyable, comfortable, relaxing, and safer compared to the interaction with human-controlled cars.

Social influence and affinity for technology interaction had the second- and third-strongest effects on behavioral intention. The positive effect of social influence on behavioral intention implies that pedestrians will be more likely to accept AVs if important people in the pedestrians' lives are more likely to support their acceptance of AVs. The positive effect of affinity for technology interaction on behavioral intention means that an increase in respondent's affinity for technology interaction increases respondents' behavioral intention to share space with AVs. The positive effect of pedestrian detection by AV suggests that the ability of AVs to detect and respond to pedestrians positively influences pedestrians' intention to share space and interact with AVs.

The negative effect of age on behavioral intention suggests that elderly people were less willing to share space and interact with AVs. The positive effect of gender (being male) on behavioral intention suggests that males were more likely to share space and interact with AVs.

The moderation effect of age on the relationship between affinity for technology interaction and behavioral intention was negative. This suggests that the relationship between affinity for technology interaction and behavioral intention is weaker for elderly people. All other interaction effects were not significant.

We found small differences in the effect sizes before and after experience. The effects of performance expectancy, social influence, and affinity for technology interaction were stronger after experience.

We will discuss the results in the subsequent section.

5. Discussion

The main objective of the present study was to develop and validate a questionnaire for the assessment of AVA for pedestrians (AVAQ-P). This step is needed as most studies have examined the acceptance of users inside AVs (i.e., passengers, drivers). We performed a four-step approach for the assessment of AVA by pedestrians to produce a statistically robust, reliable, and valid factor structure. Prior to estimating the structural path relationships between the factors influencing acceptance, and the acceptance construct itself, we subjected our questionnaire items to a PCA to explore the underlying patterns in the dataset, and reduce instrument complexity. This factor structure was then subjected to a confirmatory factor analysis to improve the reliability and validity of our questionnaire, being pivotal for further development and refinement of the questionnaire to be administered in future studies. A clear five-factor structure emerged, which resembles AVA constructs used in earlier studies.

We also found differences in the effect sizes and significance levels of the factors influencing pedestrians' AVA. Before and after AV experience, performance expectancy was the strongest factor impacting pedestrians' willingness to share space with AVs. This is in line with research documenting positive effects of performance expectancy on the behavioral intention to use AVs by users inside (Meyer-Waarden & Cloarec, 2022), and outside (i.e., pedestrians) (Kaye et al., 2022). It is likely that it is difficult for pedestrians as indirect, external road users to assess the direct benefits associated with AV use if they only interact with the external features of AVs (Zhou, Sun, Wang, Liu, & Burnett, 2023). Future research should further investigate how the perception of benefits of AVs varies between users inside and outside AVs.

Table 4
Discriminant validity test; Spearman-rank inter-construct correlation matrix, pre- and post-AV experience.

Construct	Pre Performance expectancy	Post	Pre Social influence	Post	Pre Pedestrian detection by AV	Post	Pre Affinity for technology interaction	Post	Pre Behavioral intention	Post
Performance expectancy	**0.812**	**0.866**								
Social influence	0.423 ***	0.507 ***	**0.836**	**0.866**						
Affinity for technology interaction	0.135	0.257 **	0.075	0.231 **	**0.842**	**0.854**				
Pedestrian detection by AV	0.190 ***	0.225 *	0.073	0.122	0.184*	0.210 *	**0.860**	**0.860**		
Behavioral intention	0.432 ***	0.599 ***	0.387 ***	0.548 ***	0.305 ***	0.369 ***	0.455 ***	0.447 ***	**0.974**	**0.979**

Note: $*p < 0.05$; $**p < 0.01$; $***p < 0.001$, all remaining correlations are not significant.

Table 5
Predicting the behavioral intention to share space with AVs as pedestrian, pre-and post-AV experience.

Structural path relationships Independent variable	Dependent variable	Pre	Post
Performance expectancy	Behavioral intention	0.285***	0.368***
Social influence	Behavioral intention	0.226***	0.276***
Affinity for technology interaction	Behavioral intention	0.248***	0.271***
AV-pedestrian detection	Behavioral intention	0.189*	0.141*
Age	Behavioral intention	−0.151*	−0.115*
Gender (Male)	Behavioral intention	0.196***	0.126*
Performance expectancy x age	Behavioral intention	0.082	0.102
Performance expectancy x gender (male)	Behavioral intention	−0.009	−0.025
Social influence x age	Behavioral intention	−0.039	−0.048
Social influence x gender (male)	Behavioral intention	−0.068	0.038
Affinity for technology interaction x age	Behavioral intention	−0.133*	−0.167**
Affinity for technology interaction x gender (male)	Behavioral intention	0.001	0.001
R^2		0.517	0.669

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$, all remaining correlations are not significant. R^2 represents the variance accounted for in behavioral intention.

Furthermore, we found a positive effect of affinity for technology interaction on AVA by pedestrians. In Kaye et al. (2022), personal innovativeness, which can be regarded as an alternative measure of affinity for technology interaction, did not influence pedestrians' intentions to cross the road in front of AVs. In the same vein, innovativeness, which is also conceptually related to affinity for technology interaction, did not influence respondents' intentions to use conditionally automated vehicles (O'Hern & St. Louis, 2023). It is plausible that the effect of affinity for technology interaction on behavioral intention varies as to whether respondents are inside or outside AVs.

Compared to pre-AV exposure, we also observed larger effect sizes of performance expectancy, affinity for technology interaction, and social influence on AVA by pedestrians after their experience. In (Xu et al., 2018), direct experience with AVs increased the perceived usefulness of AVs. Our finding suggests that respondents' experience with AVs can influence respondents' cognitive and affective beliefs (i.e., performance expectancy, social influence), and technology enthusiasm. Thus, the familiarization of respondents with AVs through videos (and possibly participation in questionnaires) which emphasize the advantages of AVs and its social acceptance might be important strategies to promote AVA by pedestrians.

Moreover, our analysis led to the development of the construct 'pedestrian detection by AV,' which captures the AV's ability to detect and respond to road users. The detection of road users by AVs is a central theme in how road users share space and interact with driverless AVs (Ackermann, Beggiato, Schubert, & Krems, 2019; Zandi, Singer, Kobbert, & Quoc Khanh, 2020). We recommend future research to contribute to the conceptualization and operationalization of this construct.

We could not test our hypothesis pertaining to the effect of comfort, hedonic motivation, and well-being on pedestrians' AVA due to measurement problems (i.e., the items representing comfort, hedonic motivation, and well-being clustered on the PCs that we labelled as 'performance expectancy', or had loadings lower than 0.40). The operationalization of well-being was based on prior research (Nordhoff et al., 2023), which has shown that AVs can improve individual's well-being by making travelling more relaxing, and reducing stress and aggression (anger) on the road (Kim et al., 2024; Nordhoff et al., 2023). Existing scales, such as the Driver Anger Scale (Deffenbacher, Oetting, & Lynch, 1994), or Satisfaction with Travel Scale (Singleton, 2019) are useful instruments to measure users' emotions in the context of transport. However, they are limited as they do not explicitly measure road users' mental health in the AV usage context. Moreover, our operationalization of well-being/mental health specifically reflects the AV-pedestrian interaction context. Future research could develop more generic items to measure well-being/mental health (see Schwing et al., 2025).

We found that gender had a significant effect on the behavioral intention. Male pedestrians were more likely to intend to share space and interact with AVs, which supports the results of studies conducted with AV drivers (Louw et al., 2021). In Li et al. (2023), the effect of gender on pedestrians' intentions to share the road with AVs was not significant. The negative effect of age on behavioral intention implies that elderly pedestrians were less likely to intend to share space and interact with AVs. This finding is plausible as elderly respondents are more vulnerable than younger pedestrians due to their physical fragility and corresponding limitations (Doulabi, Hassan, & Li, 2023). Kaye et al. (2022), Deb et al. (2017), and Li et al. (2023) found that younger pedestrians reported a higher willingness to cross the road in front of AVs. On the other hand, elderly pedestrians may benefit more than younger pedestrians from the deployment of AVs due to the expected safety benefits of AVs.

Most of the relationships in our two models were not moderated by age and gender. This mirrors previous study findings with drivers of AVs, which, however, did not estimate changes in the effects due to experience (Nordhoff et al., 2020). Age moderated the relationship between performance expectancy and behavioral intention, which suggests that the relationship between performance expectancy and behavioral intention is stronger for elderly people. The implication of this finding is that the promotion of the benefits associated with the deployment of AVs may be an effective way to promote the intention to share space with AVs among elderly respondents. The interaction effect of age on the relationship between affinity for technology interaction and behavioral intention was negative. This implies that the relationship between affinity for technology interaction and behavioral intention becomes weaker with age, which is a plausible finding that confirms previous studies.

5.1. Limitations and future research

First, the binary sample of our study is relatively small, which may not be representative of the general German pedestrian population. We recommend future research to repeat the study with a larger, more representative and gender-diverse population of pedestrians, considering cross-cultural differences in AVA by pedestrians.

Second, each respondent viewed videos involving an AV-pedestrian crossing situation. While we selected one of the most common and potentially safety–critical scenarios where AVs can interact with pedestrians, choosing videos depicting one main interaction scenario limits the generalization of the study's results to other AV-pedestrian interaction scenarios. We recommend future research to examine the transferability of the study's results, varying the number and type of traffic situations in videos or augmented or virtual reality environments, or, preferably, through real-world user studies. As real-world studies are resource-intensive, studies using videos or augmented or virtual reality can be used first to test study design and feasibility.

Third, the present study contributed to the validation of the AVAQ-P. Future research should assess to what extent this instrument is generalizable to other vulnerable road user groups, such as cyclists (AVAQ-C), motorcyclists (AVAQ-MC), or users of other micromobility solutions (AVAQ-LEV), or if it generalizes even further to vehicle and technology interaction (AVAQ-AI).

Fourth, the study did not assess the test–retest reliability or the sensitivity of the instrument to changes. This is a shortcoming, which should be addressed by future studies.

Fifth, while we established discriminant and convergent validity, our measure could be further strengthened by additional validity tests for convergent and criterion validity. For example, future research should investigate how our measure is in agreement with existing scales for the assessment of pedestrian attitudes and behavior, such as the Pedestrian Environmental Quality Index (PEQI) created by the San Francisco Public Health Department (NACTO, 2025).

Sixth, the present study has limited the conceptualization of the AVA by pedestrians to the intention to share space and interact with AVs rather than considering specific types of safety–critical interaction scenarios (e.g., crossing the road in front). Future research should contribute to the conceptualization and operationalization of the AVA by pedestrians, including other dimensions to examine how acceptance varies across interaction scenarios.

Seventh, we only presented the factors that are relevant for the context of the present study. Prior research has shown that AVs may need to satisfy other needs, such as needs for competence, relatedness, speed, reliability or accessibility (see Fu, 2024; Kim et al., 2024). Future research should identify these additional needs and examine how they can be positioned within the context of our pyramid.

Eighth, the area of automated driving will be subject to many potential changes. It can be assumed that the public is still unsure about the extent to which AVs will be implemented, how they will look, and which features they will have (e.g., existence of steering wheel operated by a human behind the wheel). Future research should assess the extent to which this will result in changes in AVA, and the needs of pedestrians sharing space and interacting with AVs.

Ninth, while our study has advanced our understanding on the factors influencing AVA by pedestrians, little is still known about why the effects presented in our study exist. We recommend future research to examine more closely the underlying dynamics behind the drivers of pedestrians' AVA.

Finally, while our framework offers a hierarchical organization of pedestrians' needs in AV interactions, our study did not test the hierarchical component of our framework. A competing perspective suggests that need fulfilment does not follow a hierarchy but is situation-dependent and varies across populations (Frison et al., 2019). Unlike most prior research which has used cross-sectional, convenience or non-probability-based samples, future research should collect longitudinal, time series survey data from samples that resemble the national population distribution for key demographic variables, such as gender, race/ethnicity, age, education, and household income to unravel the temporal nature of our proposed framework.

5.2. Final conclusions

The present study has contributed to the development and validation of a questionnaire to measure AVA by pedestrians. As vulnerable road users, pedestrians are disproportionately involved in fatal road accidents. The AVA literature has mainly focused on understanding, modeling, and predicting AVA by direct users inside AVs (drivers, passengers). For a widespread deployment of AVs, understanding, explaining, and predicting the AVA by pedestrians is pivotal. The validity and reliability of the constructs of the instruments were confirmed. The results of structural equation modeling analysis revealed differences in the effect sizes and significance levels of the factors influencing pedestrians' AVA. The AVA by pedestrians was most strongly influenced by affinity for technology interaction, performance expectancy and social influence. The detection of pedestrians by AVs emerged as factor impacting their acceptance, reflecting a central need of pedestrians interacting with AVs. Future research should further validate the scale on a larger, more representative sample of pedestrians to support the development of an instrument that can assess the AVA of pedestrians in a standardized way over time.

CRediT authorship contribution statement

S. Nordhoff: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **M. Hagenzieker:** Writing – review & editing, Supervision, Conceptualization. **M.**

Wilbrink: Writing – review & editing, Resources, Project administration, Data curation, Conceptualization. **M. Oehl:** Writing – review & editing, Resources, Project administration, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2025.04.016.

Data availability

Data is provided

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