Factors Affecting Pedestrians' Trust in Automated Vehicles: Literature Review and Theoretical Model

Siyuan Zhou, Xu Sun, Bingjian Liu, and Gary Burnett

***Abstract*—Automated vehicles (AVs) are one critical application area of artificial intelligence (AI). However, a lack of appropriate trust can be a major barrier to successfully introducing AVs into the market. The objective of this study is to summarize and synthesize the existing literature to gain a greater understanding of factors that will potentially influence the development of pedestrians' trust in AVs over time. Since AVs will become part of a larger infrastructure system that influences more than just AV users, they should also be accepted by pedestrians and other road users. There is a need for pedestrians to form appropriate levels of trust toward AVs to achieve safe interaction with such vehicles in circumstances characterized by uncertainty and vulnerability. Consequently, factors relevant to the building of this appropriate trust must be understood. By integrating the reviewed empirical studies and related theories, a theoretical model has been proposed and developed, comprising three layers of variability in pedestrian-AV trust (dispositional trust, situational trust, and learned trust). Given that this is an emerging field of research, much still remains unknown, and this review identifies several gaps in current knowledge for each layer of trust, as well as providing suggestions for consideration in future studies. Additionally, the proposed model of pedestrian-AV trust can be useful to transportation researchers, practitioners, designers, and AV manufacturers for designing AVs and related transportation systems for the purposes of successfully integrating AVs into society, and calibrating pedestrians' trust to the appropriate level.**

***Index Terms*—Artificial intelligence (AI), automated vehicles (AVs), human-automation interaction, pedestrians, trust.**

I. Introduction

The recent rapid developments in artificial intelligence (AI) are providing unprecedented opportunities for building intelligent transport systems [1]. AI is the simulation of human intelligence processes by machines, especially computer systems [2], [3], which can be applied to most aspects of transport systems of the future, including road infrastructures and vehicles [1]. As an important application area of AI, automated vehicles (AVs) rely heavily on AI techniques (e.g., machine learning and deep learning [1], [4]) to interpret a vehicle's actions and the surrounding environment (e.g., traffic signs, other road users) and to make driving decisions [5]. According to the Society of Automotive Engineers (SAE) [6], the degree of driving automation can be categorized into six levels, ranging from Level 0 (no automation) to Level 5 (full automation). AVs (SAE level 3 and higher) are able to reduce or remove human involvement from the task of monitoring the driving environment and operating the vehicle, allowing drivers to participate in nondriving related activities [6]. As AI technologies, along with the functioning of all AV sensors (including cameras, lasers, and radar scanners [7]), become more advanced and matured, automotive manufacturers have set goals of commercializing AVs by the end of this decade [8]. AVs are expected to cause a dramatic shift in how transportation systems operate around the world, and will bring potential benefits to citizens and society as a whole, such as a reduction in the number of traffic accidents and fatalities, alongside reduced levels of congestion and fuel consumption [1], [9]. They will also contribute to the proliferation of new forms of mobility, such as offering driverless shuttlebus or robotaxi-like services, particularly for the first and last mile of a journey [10].

Although there is a strong desire among manufacturers and organizations to introduce AVs into the marketplace, a lack of appropriate trust from the general public is currently one of the key obstacles to the practical realization of AVs [2], [11]. Many previous studies have highlighted the importance of trust in the adoption stage of new technologies [12]–[14], and trust is recognized as a primary determinant of acceptance of AVs [11]. The vast majority of existing research on trust in AVs has been approached mainly from the perspective of users (passengers), while giving less attention to trust between pedestrians and AVs. Because AVs will become part of a larger infrastructure system, which will have an influence on AV users and other members of society, they should also be properly trusted by both pedestrians and all other road users to ensure safe and pleasant interaction [15]. It is worth noting that the trust-related issues deriving from pedestrian interaction with AVs can be very different from those inside such vehicles [16]. For this reason, there is a need to emphasize the topic of pedestrian-AV trust [15], [16].

One commonly used definition of trust in recent AV literature is "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (p.54) [17]. It should include a trustor to give trust, a trustee to accept trust and a goal that is to be achieved through relevant behaviors or actions [18], [19]. The above definition also makes clear that trust often exists in an uncertain and risky environment [17]. In this case, we focus specifically on

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pedestrians' trust in AVs, so that the pedestrian and the AV play the roles of trustor and trustee, respectively. To achieve safe and pleasant interaction in circumstances of vulnerability, pedestrians need to build and develop appropriate levels of trust in AVs [15]. It is noteworthy that, in the field of trust research, the major goal is not to maximize trust, but rather to precisely adjust the trust levels of people to a system's actual capabilities and performance (i.e., calibration of trust), while taking into account the context of its use [17], [19]. The levels of trust should reflect pedestrians' accurate understanding about the degree of imperfection inherent in AI systems, and thereby lead to the adjustment in their interactions with AVs to maintain safety [20].

A number of recent studies have indicated that pedestrians are likely to have inappropriate levels of trust in AVs, including overtrust (trust exceeding system capabilities) and distrust (trust falling short of system capabilities) [21], [22], [23]. Such miscalibrated trust can manifest itself in different ways. On the one hand, pedestrians with overtrust tend to underestimate the risk of the occurrence of deficient actions and the consequences of such errors in AVs (including the deficiencies in AI systems or in other sensors) [24]. For instance, some pedestrians may trust that the AVs will always stop for them, and thus may attempt to cross a road with a higher level of risk when they see an approaching AV [25]. However, it should be noted that AVs will probably convey false (or at least risky) information to pedestrians [10]. On the other hand, when the trust levels of pedestrians are lower than the actual objective trustworthiness of AVs, then distrust appears [17]. In previous research, the lack of experience and knowledge of AVs, coupled with low awareness about AI technology, are key factors for distrust toward AVs, which can restrict people's ability to envision the potential long-term benefits brought by these vehicles [26], [27]. Further research is therefore required to prevent both overtrust and distrust toward AVs.

Before seeking solutions to calibrate trust, it is essential to first understand how pedestrians may develop and change their level of trust in AVs over time. One perspective of research is to learn the trust formation process (e.g., any interplay between the analytic, analogical, and affective processes [17]) whereas another perspective is to focus on the contributing factors of trust [28]. Many researchers have suggested that gaining deeper insights into factors that build appropriate trust is important for a better understanding of the same [12], [29]. Although there are already numerous studies concerning the factors related to trust development in the field of automation and AVs [12], [19], [30], it has not yet been systematically studied and explored in the context of pedestrian-AV interaction. Because pedestrians often interact with (but do not use) the external features of AVs, it can be reasonably assumed that the affecting factors on pedestrians' trust would be different from those stated in past literature, which primarily examine trust from the perspective of users of AVs. On this basis, the purpose of this study is to explore and synthesize the existing literature, with a view to providing a clearer understanding of which factors are possibly responsible for the development of pedestrians' trust in AVs over time. We have contributed to this topic by proposing and developing a theoretical model that comprises three layers of variability relevant to pedestrian-AV trust.

II. Methods

This study systematically reviewed the literature published in English (including journals and conference proceedings) regarding trust in automation, trust in AVs, and the interaction between vehicles and pedestrians. Four library databases (ACM Digital Library, IEEE Explore, SAGE Journals, and ScienceDirect) were used for an initial search of articles published from January 2000 to June 2021, with the use of multiple combinations of key terms, such as trust, trust in automation, AVs, and pedestrians. The words automated, autonomous, driverless and self-driving, car and vehicle were treated as synonyms. To find articles of interest, the key terms and their synonyms were combined using Boolean operators "AND" and "OR," such that the SAGE Journals search used "trust" AND "pedestrian*" AND ("automated car*" OR "automated vehicle*" OR "autonomous car*" OR "autonomous vehicle*" OR "driverless car*" OR "driverless vehicle*" OR "self-driving car*" OR "self-driving vehicle*"). We used the following inclusion criteria.

1) Examines the topic of trust or pedestrian-vehicle interaction from the viewpoint of human factors.
2) Identifies factors associated with trust or trust-related behaviors when interacting with automated systems.
3) Reports new findings that can, directly or indirectly, contribute to the study of pedestrians' trust in AVs.

Fig. 1 shows the flowchart of the selection process for the articles included in this literature review. The initial search yielded 1971 results. After removing duplicate publications ($N = 278$) and scrutinizing those based on their title and abstract, a total of 75 papers were identified for full text review. At this stage, most articles ($N = 1618$) were excluded because: 1) they emphasized technical, ethnical, political, or other aspects of the topic rather than human factors; 2) they were irrelevant to the topic (e.g., some studies focus on examining the willingness of users to pay for AVs, or the general attitude of users toward AVs). Of the 75 articles, only 20 met the selection criteria and were eligible for this study. These papers were carefully chosen according to their relevance to the topic, source of publication, and the originality of their findings. As explained in Fig. 1, the main reasons of exclusion were as follows.

1) There was a lack of a detailed exploration into the factors related to pedestrian-AV trust.

2) Some factors (such as customization of the system) identified in other domains could not be applied to the process of trust building between pedestrians and AVs.

3) Some of the findings were not novel.

To supplement this list, additional articles were identified by reviewing the reference lists of already included publications, as well as a secondary web search (using Google Scholar) with multiple keywords. The secondary search process led to the identification of seven eligible articles, resulting ultimately in a total of 27 papers being included in this review (see Table I). The reviewed articles were classified into five general themes as follows:

1) trust in automation or other related domains;
2) drivers' or users' trust in AVs;
3) pedestrians' trust in AVs;
4) the interaction between pedestrians and conventional vehicles;
5) the interaction between pedestrians and AVs.

TABLE I
SUMMARY OF REVIEWED LITERATURE

No	Author, Publication year, Country	Context	Key Methodology	Main Findings
Trust in automation (or other related domains)				
1	Hengstler et al. (2016), [18] Germany	Examine nine case studies in the industries of transportation and medical technology to see how trust in applied AI is developed.	Case study	Trust in applied AI often evolved along two dimensions: one via trust in the technology, while the other was via trust in the innovating company and communication.
2	Hoff and Bashir (2015), [19] US	Review a range of empirical research studies and propose a three-layer model that conceptualizes the variability of trust in automation.	Review	There were three layers of variability in human-automation trust (i.e., dispositional trust, situational trust and learned trust).
3	Lee and See (2004), [17] US	Develop a conceptual model that integrates the findings of the literature about trust in automation.	Review	This review shed light on the influence of context, automation characteristics and cognitive processes on trust development.
4	McKnight et al. (2002), [31] US	Develop and evaluate a model of initial consumer trust in the context of electronic commerce.	Questionnaire	The perceived reputation of a web vendor and the perceived quality of their website were important in the initial trust building process.
5	Schaefer et al. (2016), [30] US	Use meta-analysis to synthesize and assess the literature concerning human trust in automation.	Meta-analysis	They identified three moderators (human, automation and environment). Findings provided a quantitative summary of factors affecting trust in automation.
Drivers' or users' trust in AVs				
6	Forster et al. (2018), [32] Germany	Explore the effects of information about OEM's (original equipment manufacturer) branding and reliability on user trust and acceptance of CAD (conditionally automated driving) functions.	Video watching	The reputation of the OEM did not directly facilitate trust but was able to contribute to the processing of other information (such as reliability information about the automation).
7	Khastgir et al. (2018), [33] UK	Explore the influence of static knowledge about the automation capability of the system on trust in a driving context.	Driving simulation	There was an increase in trust towards the automated system when the knowledge of its true capabilities and limitations was introduced to the participants.
8	Lazányi and Maráczi (2017), [34], Hungary	Focus on dispositional trust and explore the behavior and motivation of young adults regarding the use of AVs.	Questionnaire	The individual difference in dispositional trust could influence how people interpret information and feedback, as well as their willingness to interact with AVs.
Pedestrians' trust in AVs				
9	Deb et al. (2017), [15] US	Analyze pedestrians' receptivity of AVs by creating and validating a pedestrian receptivity questionnaire for AVs.	Questionnaire	It built a survey to assess pedestrians' receptivity of AVs, consisting of 16 survey items based on attitude, social norms, trust, compatibility, and system effectiveness.
10	Faas et al. (2021), [35] Germany	Investigate how different eHMIs (status eHMI and intent + status eHMI) affect trust calibration and crossing behavior of pedestrians.	Video Watching	A status eHMI might lead pedestrians to overtrust AVs, so that additional intent messages were needed to support trust calibration in AVs.
11	Holländer et al. (2019), [21] Netherlands	Explore and investigate the effect of the AV's malfunction or misleading information shown on the display on pedestrians' trust.	VR simulation	The malfunction of an eHMI (external human-machine interface) was likely to make pedestrians neglect its errors and to aggravate the influence of overtrust.
12	Jayaraman et al. (2019), [16] US	Investigate whether the driving behavior of AVs and traffic signals can affect pedestrians' trust in AVs and their trust-related behaviors.	VR simulation	Aggressive AV driving behavior could significantly diminish pedestrians' trust in AVs. People expressed more trust in AVs at signalized crosswalks.
13	Kaleefathullah et al. (2020), [36] UK	Investigate the misleading behavior caused by the AV that is equipped with an eHMI in the form of a light band.	Pedestrian simulator	The inclusion of eHMIs could lead people to over-rely on the eHMI and give less attention to the vehicle-intrinsic cues.
14	Reig et al. (2018), [26] US	Undertake an interview-based field study of AVs with pedestrians in nine locations of the United States where Uber AVs are routinely tested.	Interview	Pedestrians' trust in AVs could be affected by their favorable interpretations of a vehicle brand, and further facilitated by their knowledge of AVs.
Interaction between pedestrians and conventional vehicles				
15	Rasouli and Tsotsos (2020), [37], Canada	Review studies on pedestrians' behavior and identify a range of factors that may account for the differences in their behavior.	Review	The social factors (e.g., group size) could alter the way in which pedestrians behaved at crosswalks.
16	Zileli et al. (2019), [38] UK	Observe and use behavior coding to capture the characteristics of interaction between pedestrians and conventional vehicles.	Observation	The collective behaviors, time course of interactions and speed changes of vehicles, could all exert an important effect on the decision-making process of pedestrians.
Interaction between pedestrians and AVs (including the design of eHMIs)				
17	Ackermans et al. (2020), [39] Netherlands	Investigate how the presence of a visible sensor system and an eHMI on an AV may affect pedestrians' behaviors and attitudes.	VR simulation	The presence of an eHMI was able to communicate the intention of an AV clearly, thus resulting in a more positive experience and more efficient crossing decisions.
18	Deb et al. (2018), [40] US	Determine external features on the AV and investigate pedestrians' suggestions for which features can affect their behaviors and attitudes.	VR simulation	The findings revealed insights into pedestrians' ratings for various external features, their crossing behaviors in front of AVs and the effect of demographic factors.
19	Dey et al. (2019), [27] Netherlands	Explore how the road-crossing behavior of pedestrians may be affected by driving modes, external appearances and driving behaviors of vehicles.	Wizard-of-Oz simulation	The results suggested that in situations when the intent of the vehicle was unknown, there were differences in pedestrians' road-crossing willingness between two types of vehicles (under manual and automated mode) as a result of the differences in their appearance.

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20	Faas et al. (2020), [41] Germany	Investigate how different information on light-based eHMIs affects pedestrians' informational needs under different traffic situations.	Wizard-of-Oz simulation	Participants preferred to be informed about the status and intention of the AVs, but not the vehicle's perception of the surrounding people.
21	Holländer et al. (2019), [42] Netherlands	Investigate the effect of eHMIs on the crossing behavior of pedestrians and the time required for their decisions to cross the road.	VR simulation	The presence of eHMIs was able to dramatically reduce pedestrians' decision time when crossing, as well as promoting comfort, trust and acceptance in AVs.
22	Mahadevan et al. (2018), [43] Canada	Create four prototype interfaces for pedestrian-AV interaction and undertaking two user studies to evaluate their usefulness in helping pedestrians to make street-crossing decisions.	Wizard-of-Oz simulation	The interfaces communicating the AV's intention and awareness were suggested to use a combination of modalities (e.g., visual, auditory, and physical cues), and could exist in both the vehicle and the environment.
23	Nuñez Velasco et al. (2019), [44] Netherlands	Explore how the physical appearance of an AV and the presence of eHMIs affect the crossing intention of pedestrians.	VR simulation	Participants who had a higher level of knowledge about AVs tended to exhibit greater trust in AVs. Moreover, pedestrians with higher trust level showed more intent to cross the road.
24	Palmeiro et al. (2018), [22] Netherlands	Investigate the effect of eHMIs on the crossing behavior of pedestrians and the time required for their decisions to cross the road.	VR simulation	The presence of eHMIs was able to dramatically diminish pedestrians' decision time to cross, as well as promoting comfort, trust, and acceptance in AVs.
25	Rahman et al. (2021), [45] US	Investigate how pedestrians perceive AVs on the basis of their knowledge and real-world road sharing experiences with AVs.	Interview	There was a general lack of trust in AV technology among respondents. The AV technology demonstration projects or awareness programs could be, therefore, implemented to improve pedestrians' trust in AVs.
26	Rettenmaier et al. (2020), [46] Germany	Develop and evaluate different types of eHMIs that are able to communicate the intention of AVs to other road users.	Driving simulation	The eHMIs could distract other road users by attracting their attention during the interaction. The eHMIs were recommended to be used only under unregulated scenes.
27	Weber et al. (2019), [47] Germany	Conduct three VR studies in Germany, the US and China to examine the potential of eHMIs across different cultural contexts.	VR simulation	Certain eHMI types that had positive influences in Germany and the US could be inappropriate for Chinese pedestrians. Moreover, eHMIs were suggested to be used only in already safe states of the AV.

III. Overview of Literature

As indicated above, a total of 27 papers were included in this literature review. Five papers ([17], [18], [19], [30], [31]) were concerned with trust in automation or other related domains (such as electronic commerce) in a general sense. These articles presented a general overview of how trust in automation has developed. Some provided the framework for discussing the factors that might influence trust in automated systems, which could be applied to a wide range of situations [19], [30]. There were three main categories of variability in human-automation trust, namely the human, the automated system, and the environment [19], [30]. These variables could be organized into three different layers of trust, including dispositional trust, situational trust, and learned trust [19]. It appears that people's trust toward an automated system is largely determined by their subjective perceptions (e.g., based on their personal experience and expectations), rather than by the actual objective trustworthiness of a system [17]. This suggests that even a well-designed and operated system may not necessarily gain the trust of humans. Hence, when compared to the automated system and the environment, the human element (such as the character or nature of an individual) is likely to play the most important role in the trust-building process [30].

Three additional papers ([32]–[34]) discussed trust in AVs specifically from the viewpoint of drivers or users. Although these studies did not directly investigate trust factors from the perspective of pedestrians, they still provided valuable insights into how user trust was affected by different variables in the context of AVs, such as the original equipment manufacturer's (OEM) reputation [32], and the knowledge held by users [33]. By understanding how these factors were linked to the change and development of users' trust in AVs, we could better apply them to the pedestrian-AV interaction and see if they would exert similar influences on pedestrians' trust toward AVs.

Furthermore, only a few studies ([15], [16], [21], [26], [35], [36]) specifically examined trust in AVs from the perspective of pedestrians. The researchers have identified a variety of factors that had a direct impact on pedestrians' trust in AVs, including the driving behaviors of AVs [16], the presence of traffic signals [16], the vehicle brand [26], as well as the pedestrians' knowledge of AVs [26]. It is also worth noting that people tend to overtrust AVs after multiple exposures to the external human-machine interfaces (eHMIs) on the front of an AV [21], [36]. Moreover, Deb *et al.* [15] developed a questionnaire as a potential tool for evaluating pedestrians' receptivity toward AVs, which could be an essential source of inspiration in the study of pedestrian-AV trust.

The review also consisted of two papers ([37], [38]) relevant to the interaction between pedestrians and conventional vehicles. They presented information and evidence about pedestrians' behaviors in existing traffic environments and indicated the implications of these findings for the design of AVs and related transport systems. It was found that social factors (including collective behavior and group size) play an important role in pedestrian-vehicle interaction, and thus, may need to be given adequate attention.

Lastly, 11 papers ([22], [27], [39]–[47]) were specific to the investigation of pedestrian-AV interaction. Each of these studies considered the effect of eHMI on pedestrians' attitudes and behaviors, although several did not directly investigate trust and its influencing factors, but rather focused on trust-related behaviors, such as willingness to cross the road [27] and the length of time spent crossing the road [41]. Some factors that are able to facilitate trust-related behaviors of pedestrians may have

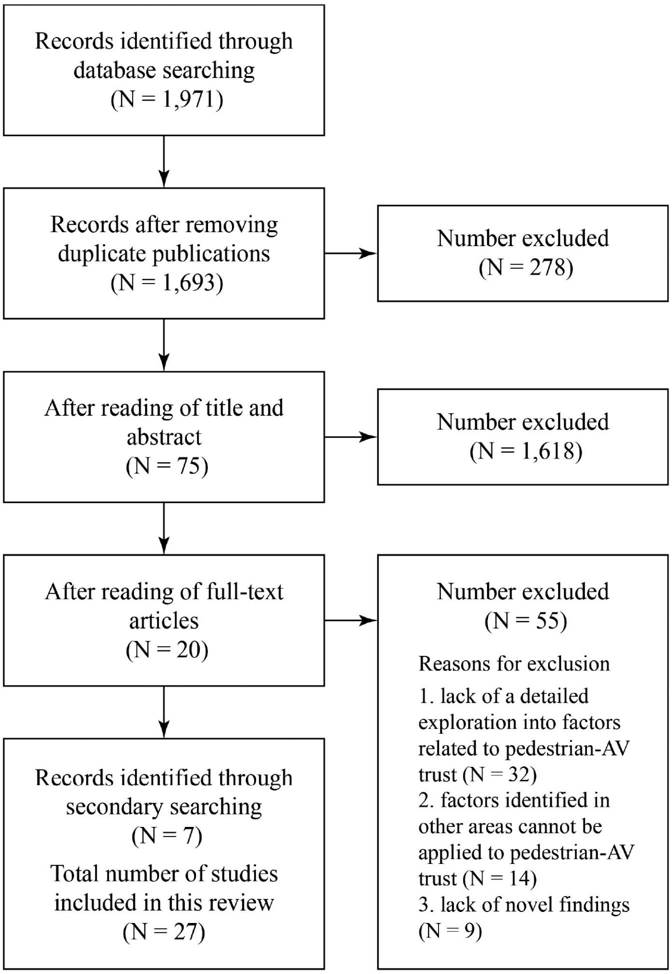

Fig. 1. Flowchart of the article selection process.

the potential (though there is no guarantee of this) to contribute to the development of appropriate levels of trust.

IV. Theoretical Model

A synthesis of the literature shows that there are three broad categories of variability in pedestrian-AV trust, including the human (pedestrians), the automation (automated driving systems), and the environment. Based on the reviewed empirical studies and related theories, the factors that may influence pedestrians' trust in AVs have been integrated into a theoretical model. In line with the work of Hoff and Bashir [19], this model reflects the following three different layers of trust: dispositional trust, situational trust, and learned trust (see Fig. 2).

A. *Dispositional Trust*

Dispositional trust refers to the overall long-term tendency of a pedestrian to trust AVs, independent of situations or moments [19]. Unlike situational trust and learned trust, it is a relatively stable characteristic, cultivated under the influence of biological and environmental factors [19], [34]. Individual differences in dispositional trust can affect how people interpret information and feedback, as well as the degree of their willingness to engage with AVs [34], [48]. A certain level of dispositional trust is, therefore, needed to facilitate positive interactions between pedestrians and AVs, especially at the initial encounter stage [34]. This review reveals that there are two main sources of variability in this most basic layer of pedestrians' trust: age and gender.

Age: Several previous studies have shown that the age of pedestrians is a significant factor relevant to their level of trust in AVs. Cognitive changes and cohort effects (or a combination of both factors) may account for age differences in trust, which can affect the way in which people of different ages assess the trustworthiness of AVs [19]. In general, younger pedestrians are more receptive to AVs than their older counterparts, and they will express a higher degree of enthusiasm about AV technologies [15], [40]. By contrast, older pedestrians seem to be more concerned about the reliability and safety of new, but unproven, technology (such as AI systems), and they are likely to exhibit greater caution when interacting with AVs [15].

Gender: Gender plays a vital role in shaping pedestrians' trust in AVs. In general, male pedestrians tend to show greater trust and more positive attitudes toward AVs [15]. A questionnaire study by Deb *et al.* [15] revealed that males often perceived a higher level of safety in AVs, and found it easier to interact with AVs, when compared to females. Kyriakidis *et al.* [49] also found that men tended to be less worried than women about automation failures of AVs. Further studies may be required to explore whether consistent gender differences exist with respect to pedestrians' trust in AVs.

B. *Situational Trust*

The formation and development of trust can vary greatly in different situations. According to Hoff and Bashir [19], there are two central sources of variability in the situational trust layer: the external environment (i.e., external variability) and the internal, context-based characteristics of pedestrians (i.e., internal variability). Most of the published literature only covers the external environmental factors but gives less attention to the internal variability (e.g., the mood and attentional capacity of pedestrians [19]). The existing literature shows that traffic signals are one important external factor related to situational trust in pedestrian-AV interaction.

Traffic signals*:* A recent study by Jayaraman *et al.* [16] focused on how contextual elements, such as traffic signals, may affect pedestrians' trust toward AVs. The results of their research showed that pedestrians generally expressed more trust in AVs at signalized crosswalks than at unsignalized crosswalks [16]. This finding is based on the premise that AVs are expected to be law-abiding (e.g., stopping at red lights) under all circumstances, regardless of their set driving styles [50]. Consequently, it can be seen that the presence of traffic signals is able to enhance trust in AVs, by determining the right-of-way and indirectly communicating the intention of AVs to pedestrians [16]. It may also help to moderate the negative effects on trust of aggressive driving of AVs [16].

C. *Learned Trust*

Learned trust usually represents a pedestrian's evaluation of a system, based on past experience or current interactions [19]. There are two major categories of learned trust: initial and

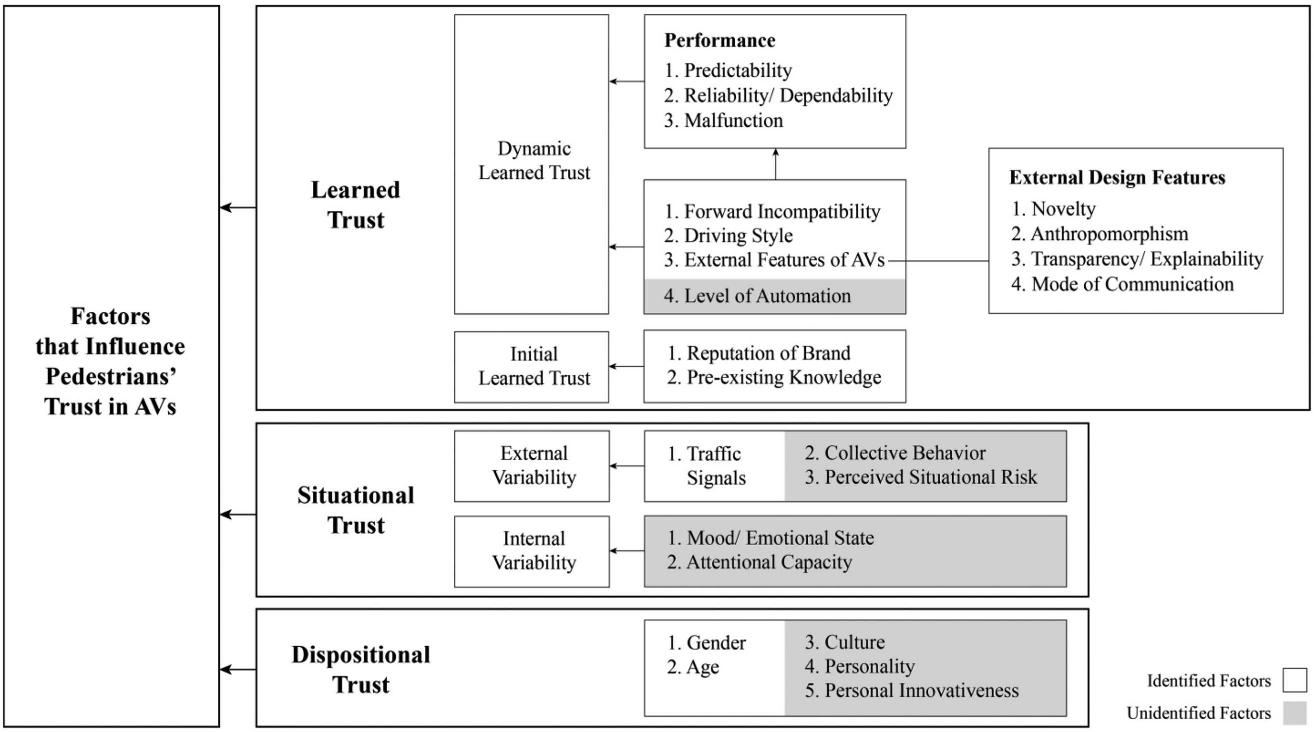

Fig. 2. Full model of factors affecting pedestrian-AV trust (hollow box: the factors that have been already identified in the existing literature; solid box: the potential factors that need to be further explored and investigated in future studies).

dynamic. Initial learned trust normally refers to the trust levels of pedestrians prior to interacting with AVs [19]. It is important to elicit people's willingness to engage with such new technologies in situations where common perceptions of risk should be overcome [18], [31]. The initial learned trust of pedestrians can be affected by brand reputation and pre-existing knowledge.

Reputation of brand: Since most pedestrians will not have had any previous actual interaction experience with AVs, their level of trust is likely to be biased by the reputation of the OEM. Past studies in other domains (such as electronic commerce) have demonstrated that a highly perceived reputation could positively contribute to the building of trust [31]. However, this trust can decline rapidly when there are noticeable errors in the system [19]. When taking a closer look at the pedestrian-AV trust, an interview-based study by Reig *et al.* [26] demonstrated that pedestrians' trust in AVs can be affected by a favorable interpretation of the company's brand. The OEM's reputation may also help pedestrians by facilitating the processing of certain information (such as reliability information about AVs) [32]. For instance, it was found that the salience of the brand (e.g., BWM and Tesla) can lead people to focus more on analogous information processing [32]. Although these studies suggest that the brand reputation of AVs can relate to the initial learned trust of pedestrians, additional research is needed.

Pre-existing knowledge: Pre-existing knowledge about the performance, process and purpose of AVs can help guide the formation of initial learned trust for pedestrians [18]. Several recent studies have shown evidence that misinformation could be the greatest factor causing the mistrust in AVs prior to an actual interaction [18], [26]. Research by Khastgir *et al.* [33] also highlighted that inaccurate information conveyed by external sources (such as by media and marketing) could potentially lead to both overtrust and mistrust toward AVs. Furthermore, pedestrians may gain prior knowledge about AVs from their past experience with a similar technology or other transport modes (e.g., aviation) [19], [44], [51]. For instance, Rasouli and Tsotsos [37] pointed out that pedestrians who were familiar with the communication technology tended to exhibit higher levels of trust in the AV (with an intent display) than those unfamiliar with related technology. Therefore, in the stage when knowledge is still low, AVs should be introduced stepwise into the market, allowing for gradual social learning [45], [52]. It is crucial to convey the designer's assumptions about the safe boundaries of the AI system to pedestrians for the purposes of creating appropriate levels of trust in AVs [33]. Businesses can achieve this by reinforcing communication (such as through publicity about AI technology and AVs), as well as increasing the transparency of AV development processes [18], [26].

Dynamic learned trust represents the trust levels of pedestrians once they begin interacting with AVs, and this may change drastically during the course of an interaction [19]. Because the automated systems of AVs are likely to perform variably, pedestrians may adjust their trust in response to the real-time performance of AVs. This fluctuation of trust can, in turn, influence the way in which pedestrians and AVs interact [17], [19]. The current literature identifies three essential factors associated with the development of dynamic learned trust: forward incompatibility, driving style, and the external features of AVs. These factors may have an influence on how pedestrians perceive the performance of AVs.

Forward incompatibility: One of the causes of misaligned trust of pedestrians toward AVs is forward incompatibility (i.e., the lack of human cues and mannerisms during the interaction between pedestrians and AVs) [53]. For instance, the passenger present in the operator seat of the AV is likely to undertake nondriving activities (e.g., reading a newspaper) and will fail to interact with pedestrians in an engaging manner. In this sense, the reliability of established pedestrian-driver communication practices, such as eye contacts or gestures, is adversely affected. Research by Palmeiro *et al*. [22] demonstrated that pedestrians were inclined to lack trust and would hesitate to cross the road under such circumstances.

Driving style: The driving style of AVs plays a crucial role in the development of dynamic learned trust. Driving style often refers to a habitual way of driving and involves decisions with regard to a variety of driving characteristics, including vehicle speed, acceleration, and distance from other objects [29], [54]. It has recently been viewed as an implicit form of vehicle communication, which is capable of conveying the AV's intent to pedestrians, such as through the use of speed and yielding behavior [16], [24]. This means that pedestrians can use speed or yielding behavior either as data coming from the vehicle, or as a potential communication tool with AVs [38]. A pilot study by Jayaraman *et al.* [16] indicated that AVs were trusted more when they performed in a defensive style, while an aggressive driving style would significantly diminish the level of pedestrians' trust in AVs.

External features of AVs: Design features of external AV appearance and eHMIs can have a significant impact on dynamic learned trust of pedestrians toward AVs. The external features of AVs are one important consideration. Numerous studies have shown that the availability of eHMIs has the considerable potential to raise the level of trust of pedestrians, particularly in less structured environments (e.g., at an unsignalized zebra crossing) [40], [42], [55]. However, it is noteworthy that people may overtrust eHMIs after some time of exposure to such an interface [21], [35], [39]. For example, research by Ackermans *et al.* [39] highlighted that the pedestrians are likely to rely excessively on the explicit information on the eHMI, once they have understood how the interface functions. The implicit cues of the AV (e.g., vehicle movement) tended to be neglected under such circumstances [36]. The current literature identifies four main external design features of AVs that should be considered in pedestrian-AV trust: novelty, anthropomorphism, transparency, and mode of communication.

Dey *et al.* [27] considered the novelty of the vehicles' appearance as a new dimension for design features and identified its potential effect on trust between pedestrians and AVs. Their interview results show that some people are more likely to perceive a vehicle with a futuristic appearance as more capable of driving autonomously. This could adversely affect pedestrians' trust in terms of technical capabilities, making them feel less confident in predicting vehicle behaviors than when interacting with conventional-looking vehicles [27]. Some researchers, however, have argued that the unconventional appearance of AVs could help pedestrians to better distinguish between conventional and AVs, as well as to form appropriate expectations about the behavior and subsequent maneuvers of AVs [10].

Anthropomorphism may also be taken into account. An AV can be anthropomorphized by adding human-like physical features or behaviors. Many previous studies have found that in complex systems with higher levels of anthropomorphism, the trust levels can be significantly enhanced [56], [57], and people also showed a less rapid decline in trust in automation following system errors [19]. On this basis, designers, researchers, and AV manufacturers have proposed several anthropomorphic features for AVs, including the eye concept (by Jaguar Land Rover), the smiling car concept (by Semcon), and the hand gesture concept, in order to better convey the vehicles' intentions to pedestrians [38], [43]. For example, in the case of the smiling car concept, a smile would light up on the front eHMI to confirm the AV's intention to give the right-of-way to pedestrians. Experts at Semcon believed that a smiling face shown on an AV could indicate its friendliness, as a result of which pedestrians would feel more comfortable when interacting with such a vehicle [40]. Nevertheless, certain anthropomorphic features on the external AV appearance (such as virtual eyes) are likely to make pedestrians feel uncomfortable and less trusting as a result of the uncanny valley effect [41], [58]. Therefore, additional research efforts should be directed toward exploring how the degree of anthropomorphism of external AV features is related to pedestrians' trust.

Another key variable is the transparency and explainability of AVs. Previous researchers have suggested that providing feedforward and feedback information about AI systems, either ahead of time or during the interaction, could be essential to trust cultivation [30]. Explainability can give people confidence that AI systems work well and help them to understand why the AVs perform in a certain way [59]. Recent studies found that AVs (with the inclusion of eHMIs) capable of informing pedestrians about their intentions and status (e.g., whether or not they were in automated driving mode) were often perceived as more transparent and reliable [40], [41]. This is likely to help to eliminate ambiguities in communication, thus allowing pedestrians to better align their expectations, and thereby foster appropriate levels of trust in AVs [35], [60]. Furthermore, it should be noted that pedestrians' trust toward AVs may not be properly developed if the information is poorly communicated, such as presenting irrelevant information or overloading individuals with information [38], [61]. For instance, research by Faas *et al.* [41] showed that informing people about an AV's perception of pedestrians situated near the vehicle did not add any value. Consequently, the optimum amount and type of information should be conveyed to pedestrians in a simple and clear manner to improve the appropriateness of trust [17], [30], [43], [46].

Lastly, because AVs may communicate with pedestrians in multiple ways (e.g., through visual, auditory, or haptic cues [62]), different modes of communication can possibly result in different levels of trust between pedestrians and AVs [19]. Most recent researchers have placed emphasis on the visual modes of communication, including texts, symbols, and anthropomorphic elements [25], [39], [40], [42]. For example, research by Deb *et al.* [40] compared the design of four visual-based eHMIs on the front of AVs (i.e., a walking silhouette, "braking" in text, a flashing smile, and a no-visuals feature), and investigated their influences on pedestrian-AV interaction. It was found that the eHMIs featuring a walking silhouette and the "braking" text were perceived by young pedestrians (aged 18–30 years) as significantly more trustworthy than the smile and the no-visual concepts [40]. Their findings shed light on how the different visual modes of communication might affect pedestrian trust toward AVs. Since the effect of auditory and haptic modes on pedestrian-AV trust have been less explored in the existing literature, additional empirical studies should be conducted as a basis for providing further insights into the role of various communication styles in the trust building process.

Furthermore, it should be noted that the three factors identified above are able to alter how pedestrians perceive their performance and may indirectly affect their learned trust [19]. It is important that the trust levels of pedestrians should be precisely adjusted to reflect the AV's actual capabilities and performance [17]. Several key aspects of the performance of AVs have been studied and mentioned in the existing literature. First, many studies have highlighted how the predictability of an AV is essential for trust development in pedestrian-AV interaction [19], [40], [41]. Predictability can be defined as the extent to which the behaviors of an AV are consistent with the expectations of pedestrians in a given situation [12], [19]. This suggests that if the experiences of pedestrians with AVs are able to provide predictable outcomes (such as by understanding the AV's intentions through both explicit and implicit communication, and forming appropriate expectations), then they are inclined to begin to trust AVs. Second, the reliability and dependability of an AV are also vital. Reliability refers to the ability of the AV system to perform the required functions under stated conditions for a specified period [19], whereas dependability is often described as the frequency of automation breakdowns or error messages [63]. In general, a reliable and dependable system contributes to the building of trust [17], [19]. Lastly, the malfunction of external AV features should also be taken into account. It is worth noting that a malfunction of the external display can directly influence the perception of the capabilities of the whole AV [21]. As indicated in a study by Holländer *et al.* [21], when there was a failure of only one subsystem (e.g., a malfunction of the eHMI), pedestrians were likely to consider that the entire system was faulty. This could negatively influence their trust toward AVs.

V. Future Research Directions

Three layers of variability in pedestrian-AV trust have been determined in this review, revealing a set of research directions. Given that this is an emerging field of study, much remains unknown regarding the factors and strategies required to calibrate the trust of pedestrians toward AVs. From an integrated point of view, future studies are needed to further explore how various factors in each layer are associated with miscalibrated trust (i.e., distrust and overtrust). Much of the previous literature has only considered trust in broad terms, without specifying how misaligned levels of trust in AVs might occur. Identification of factors related to the misalignment of trust in specific and concrete terms is an important prerequisite for better assessing pedestrians' trust in AVs, as well as facilitating approaches to the calibration of trust [17]. Moreover, directions for future research are suggested for each trust layer based on the findings and insights gained from the existing literature.

A. Directions for Dispositional Trust

Researchers may need to explore whether age has a relevant impact on the ability of pedestrians to calibrate their own levels of trust [19], [64]. Specifically, research is potentially required to examine whether older adults would calibrate trust differently and properly, such as when following an experience indicative of the failure of eHMIs. It is also worth investigating how pedestrians of different genders would respond differently to the external design features of AVs (e.g., anthropomorphism and the novelty of external appearances), and thereby determine whether or not consistent gender differences exist.

Culture is another potential variable for consideration in relation to pedestrians' levels of trust. Past studies have stressed the importance of culture in trust in automation [17], [19]. Although no current studies have directly investigated the role of culture in the cultivation of pedestrians' trust, research by Weber *et al.* [47] revealed that cultural differences could result in different perceptions and expectations regarding the design and the behavior of AVs. They examined the potential of eHMIs across different cultures and found that the light-band eHMI in both the US and Germany was able to help pedestrians to improve their recognition of an AV's intentions, but this was not suitable for Chinese pedestrians. Additionally, Weber *et al.* [47] also pointed out that pedestrians from different cultural backgrounds may have various mental models and expectations about a vehicle's behavior. For example, Chinese pedestrians were likely to show a lower expectancy of vehicles exhibiting yielding behavior than people in the US and Germany [47]. Therefore, such cultural differences may be relevant to the differences in pedestrians' levels of trust across various countries, and more cross-cultural studies are necessary to demonstrate and evaluate empirically the impact of culture on the building of pedestrians' trust.

In addition to the already identified factors (including age and gender) and culture, there are many other variables [such as personality and personal innovativeness (PI)] that have not been explored in pedestrian-AV trust. For instance, several previous studies have shown the relationships between some specific personality traits (e.g., neuroticism and extroversion) and dispositional trust in the domain of trust in automation [19], [65]. Furthermore, PI, which refers to the willingness of an individual to try new things in the face of unknowns, is also one of the demographic characteristics related to the receptivity of AVs [15]. Nevertheless, it remains unclear how these new variables may affect pedestrians' trust in AVs. Future studies should continue to expand on the factors associated with the dispositional trust of pedestrians toward AVs.

B. Directions for Situational Trust

There are several areas where future research is crucial for a greater understanding of underlying factors related to situational trust. First, the presence and behaviors of other pedestrians may be important in trust development because individuals are likely to use this social information, rather than their own judgments of traffic situations, when interacting with AVs [38]. A previous review by Hoff and Bashir [19] recognized the social influences on trust in automation, by showing that the attitudes of operators toward automation could be affected by the opinions and expectations of their colleagues or supervisors. This social effect may also work in the development of pedestrian-AV trust. Although there is no research directly examining the impact of such collective behavior on pedestrians' trust in AVs, a number of existing studies have provided evidence that pedestrians' trust-related behaviors are likely to be affected by their neighbors [37], [66]. For instance, Faria *et al.* [66] found that pedestrians were 1.5–2.5 times more willing to cross the road if at least one of the other pedestrians around them had already begun to cross. Moreover, based on the fact that current drivers were found to be more inclined to yield to pedestrian groups (three or more) than to individuals [37], the size of groups of pedestrians may help to moderate vehicle speed and movement, which can, in turn, influence pedestrians' risk perceptions and attitudes toward vehicles. Therefore, this socially constructed engagement with traffic deserves to be considered in pedestrian-AV interaction, and its impact on pedestrians' levels of trust should be explored further. More empirical research is needed to examine and confirm the effect of collective behavior on the building of pedestrians' trust. It also reveals an opportunity to create a more transparent interaction between pedestrians and AVs, such as by triggering the collective behaviors of pedestrians through the appropriate design of transport systems, or by encouraging the perception of collective behaviors in the actions of AVs.

Researchers should also consider the possible implications of internal, context-dependent factors (such as attentional capacity and mood [19]) on the development of the situational trust of pedestrians. For example, past research has suggested that the initial emotional state of an individual may have an impact on the trust building process [19], [67]. Pedestrians in different mood states (e.g., in either a positive or a negative mood) are likely to have different levels of trust toward AVs, so this also deserves further investigation.

Finally, since the environment often helps to determine the potential risks and benefits involved in pedestrian-AV interaction [19], it may be worth considering the influence of perceived situational risk in the cultivation of pedestrians' trust. Here, a wide range of environmental factors, such as road features (e.g., geometry and signs), weather, and light conditions, as well as traffic density, can all potentially affect pedestrians' perceptions of situational risk [37]. Thus, future studies could look at how pedestrians would trust AVs, and would rely on different cues (e.g., implicit or explicit cues exhibited by AVs), when greater situational risk is involved (such as in rainy or snowy weather conditions, or in complex road traffic situations).

C. Directions for Learned Trust

Although a number of studies have offered insights into the main factors governing the development of learned trust of pedestrians, there are still many areas on which future efforts should be concentrated. Future research could attempt to provide more empirical evidence for the impact of the different modes of communication on pedestrians' trust toward AVs. In addition to visual modes, researchers and designers are encouraged to explore the potential of using auditory cues (i.e., any form of spoken words), haptic cues (i.e., any haptics-based signals via the use of wearables, phones, or tablets) and other new forms of communication in pedestrian-AV interaction, as well as to examine their effects on learned trust. The choice for using one or multiple modes of communication should be carefully determined under different scenarios.

Since it has been highlighted in current literature that pedestrians are likely to exhibit both distrust and overtrust in AVs, there is also an urgent need for researchers and designers to explore ways to help to calibrate pedestrians' levels of trust under low- or high-trust situations. For instance, under high-trust situations (such as when pedestrians have multiple exposures to eHMIs), the approaches to preventing excessive levels of trust toward AVs through other communication means could be investigated further.

Furthermore, researchers are recommended to shift their attention from explicit communication (e.g., the design of eHMIs) to implicit communication (e.g., driving behaviors of AVs) when exploring the topic of pedestrian-AV trust. Some recent studies of pedestrian-AV interaction have shown that the AV may be able to indicate its intention to yield to pedestrians only through driving behaviors, such as deceleration cues [68], [69], or lateral deviation within lanes [70]. The role of implicit communication cues in the trust-building process between pedestrians and AVs deserves to be explored more fully in future research.

Lastly, the level of automation (i.e., from level 3 to level 5) is probably another significant factor that should be considered in the future. The key difference between level 3 and level 5 systems is the requirement to take back control of the driving task in case of take-over situations [71]. In level 3, and certain types of level 4 vehicles, people are still required to resume control by shifting from automation to manual operation within a certain time period. By contrast, level 5 vehicles are expected to be fully controlled by software and hardware, and capable of performing dynamic driving tasks independently without the presence of a human driver during an entire journey [6], [40]. Such differences in the human intervention are likely to affect how pedestrians shape their trust in AVs with different levels of automation.

VI. Conclusion

In this article, AVs are considered as an important application area of AI. The purpose of this research was to review and synthesize the findings from existing literature, with a view to gaining a greater understanding of potential factors that could influence the formation and development of pedestrians' trust in AVs over time. Through a systematic review process of existing publications, from January 2000 through June 2021, a total of 27 papers were identified and included in the analysis. There are three main contributions of this article. First, we conducted an in-depth literature review and summarized key findings from research regarding trust in automation, and trust in AVs, as well as the interaction between pedestrians and vehicles. Second, this is the first model that systematically identifies the factors that may influence trust in AVs from the perspective of pedestrians, and which organizes these variables into three broad layers (dispositional trust, situational trust, and learned trust). The proposed model of pedestrian-AV trust can be potentially useful to transportation researchers, practitioners, designers, and AV manufacturers in designing AVs from level 3 onward, and any related transportation systems. Third, this study also suggests a range of research directions, which can be the focus of further research or design practices in this domain, for the ultimate purposes of successfully integrating AVs into society, and of calibrating pedestrians' trust at the appropriate level.

Nevertheless, there are several limitations in the current literature. First, the vast majority of the reviewed studies on pedestrian-AV trust (or interaction) relied on Virtual Reality (VR) simulations or on the Wizard-of-Oz simulation technique, and they only covered a few simple scenarios (e.g., crossing the road in front of a single vehicle), which limits the realism of such studies. Thus, future work is encouraged that should be conducted with actual AVs in real road environments. Second, many existing studies have not investigated the long-term effects of trust factors. For instance, participants may have encountered eHMIs only once during an experiment, so it remains unclear how the trust levels of pedestrians would change or develop over time. Consequently, multiple trials should be conducted in long-term future studies to better understand the effects of various variables beyond the first encounter. Third, there is probably a need to investigate pedestrians' trust in AVs in a mixed traffic environment. It can be challenging to consider how pedestrians develop their trust and interact with multiple vehicles that have varying levels of autonomy (including manually driven vehicles, highly automated, and fully AVs).

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