Trust in AV: An Uncertainty Reduction Model of AV-Pedestrian Interactions

Late-Breaking Report

Suresh Kumaar Jayaraman*
University of Michigan
jskumaar@umich.edu

Chandler Creech*
University of Michigan
creechch@umich.edu

Lionel P. Robert Jr.
University of Michigan
lprobert@umich.edu

Dawn M. Tilbury
University of Michigan
tilbury@umich.edu

X. Jessie Yang
University of Michigan
xijyang@umich.edu

Anuj K. Pradhan
University of Michigan
anujkp@umich.edu

Katherine M. Tsui
Toyota Research Institute
kate.tsui@tri.global

ABSTRACT

Autonomous vehicles (AVs) have the potential to improve road safety. Trust in AVs, especially among pedestrians, is vital to alleviate public skepticism. Yet much of the research has focused on trust between the AV and its driver/passengers. To address this shortcoming, we examined the interactions between AVs and pedestrians using uncertainty reduction theory (URT). We empirically verified this model with a user study in an immersive virtual reality environment (IVE). The study manipulated two factors: AV driving behavior (defensive, normal and aggressive) and the traffic situation (signalized and unsignalized). Results suggest that the impact of aggressive driving on trust in AVs depends on the type of crosswalk. At signalized crosswalks the AV's driving behavior had little impact on trust, but at unsignalized crosswalks the AV's driving behavior was a major determinant of trust. Our findings shed new insights on trust between AVs and pedestrians.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **HCI theory, concepts and models**;

KEYWORDS

trust in automation, autonomous vehicles, pedestrian interaction, uncertainty reduction, human-robot interaction

1 INTRODUCTION

Public skepticism with regard to issues of safety remains a major barrier to the widespread adoption of autonomous vehicles (AVs). This skepticism explains why trust has been identified as a vital precursor to the acceptance of AVs. However, researchers have mostly focused on the interactions between the AV and its driver/passengers[1, 9]. The interactions between AVs and pedestrians are quantitatively and qualitatively different from those inside the AV. These differences present new problems and challenges that are distinct from the interactions between the AV and its driver.

Researchers have begun to focus on the interactions between AVs and pedestrians. This work is specifically focused on developing explicit communication interfaces such as LED message boards and speakers for conveying the vehicle's intent [7]. More recently, researchers have highlighted the need to understand how pedestrians might interpret and react to AVs in the absence of explicit communications devices [10]. Our study contributes to the literature by examining the effects of implicit communication and situational factors on the trust in AVs.

In this paper we introduce uncertainty reduction theory (URT) as an overarching theory to explain the interactions between AVs and pedestrians. In our research, trust in AVs is defined as the willingness to be vulnerable to the actions of the AV. According to URT, individuals are motivated to seek information to reduce uncertainty[2, 6]. Uncertainty is the inability to predict another's behavior for lack of information about the person or environment[2]. URT principles state that, the more uncertainty, the more people seek information to reduce it; the more information provided, the less uncertainty[2, 6]. Research has shown that trust and uncertainty are inversely related [4]. As such our research's basic premise is: *As the communication of information allows the pedestrian to predict the actions of the AV increases, so should trust in the AV.*

In this study, we identified two sources of information likely to impact uncertainty. The first source is the AV's driving behavior (defensive, normal and aggressive driving). The more aggressive the driving behavior, the more uncertainty and the less trust. The second is the traffic situation, which in our study is the type of crosswalk. Generally, signalized crosswalks should reduce uncertainty and increase trust, while unsignalized crosswalks should do the opposite. Based on the URT we derived the following hypotheses:

H1: Aggressive driving decreases trust in the AV.
H2: Signalized crosswalks increase trust in the AV.
H3: Crosswalk type moderates the impact of driving.
H4: Trust in the AV leads to more trusting behaviors.

*These two authors contributed equally to the study.

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).
HRI '18 Companion, March 5–8, 2018, Chicago, IL, USA
© 2018 Copyright held by the owner/author(s).
ACM ISBN 978-1-4503-5615-2/18/03.
https://doi.org/10.1145/3173386.3177073

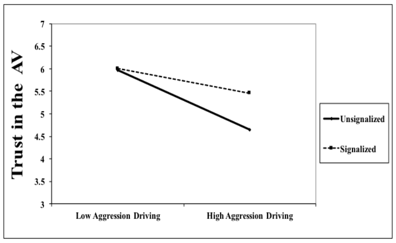

Figure 1: Moderation of Aggressive Driving by Signal condition

To test these hypotheses, we conducted an experimental user study with 30 participants. Next, we present the details of the study and our preliminary results.

2 USER STUDY

This study employed a within-subject experimental design. The participants took on the role of pedestrians in an IVE [3] utilizing a novel omni-directional treadmill [5] and a virtual reality headset. They were tasked with moving an object across a street at a mid-block crossing with several AVs approaching. There were six conditions (3 X 2) represented by the type of AV driving behavior (defensive, normal and aggressive), and the type of crossing (signalized and un-signalized). Example videos of the six conditions can be found at https://goo.gl/qQvp33. The different driving behaviors were obtained by varying the vehicle's reactions (stop, slow down, or continue at full speed) with respect to the pedestrian's discrete positional states, in addition to varying the speeds and accelerations.

We collected attitudinal and behavioral measures. The attitudinal measures include trust [8], propensity to trust, and simulation sickness which we measured through surveys. The behavioral measures collected from the simulation included average distance to collision, average waiting time, average crossing time, average jaywalking time and average crossing speed.

3 RESULTS

We conducted a manipulation check to ensure that each driving condition sufficiently varied the participant's perception of aggressive driving. The F statistic was significant ($p < .001$) with estimated marginal means and standard errors, $\overline{x}$ = 2.67 (0.216) for defensive, $\overline{x}$ = 3.44 (0.214) for normal and $\overline{x}$ = 4.24 (0.231) for aggressive driving.

We employed a mixed linear model to account for the non-independence of the data. The models testing each of the following hypotheses included age, driving experience, propensity to trust automation, and simulation sickness as control variables. H1 posited that aggressive driving would decrease trust in the AV, which was supported (β = -.24, $p < .01$). H2, which stated that signalized crosswalk would increase trust in the AV, was also supported (β = .54, $p < .001$). H3, which stated that the impact of aggressive driving on trust would depend on the type of crosswalk, was also supported (β = .56, $p < .001$). Figure 1 shows the moderation effect. H4, which posited trust in the AV will lead to more trusting behaviors, was partially supported.

The trusting behaviors of interest in this study were: reduced distance between the AV and the pedestrian, reduced waiting time before crossing, reduced crossing speed, and increased jaywalking time. We found that increased trust in AV was significantly related to reduced distance between the AV and the pedestrian (β = -.38, $p < .001$) and increased jaywalking time (β = .17, $p < .05$). However, it was not related to average crossing time (β = -.08, $p < .05$) or average crossing speed (β = .02, $p < .05$). Interestingly, we found that increased trust was associated with increased average waiting time (β = .18, $p < .001$).

4 DISCUSSION AND LIMITATIONS

Our preliminary results point to several potential contributions. First, this paper introduces URT as an overarching theory to better understand trust between AVs and pedestrians. Second, we found that signalized crosswalks greatly reduced the negative effects of aggressive driving. Third, results of this study highlight the link between trust in the AV and trusting behaviors. Finally, this study highlights the benefits of using IVEs to study human and AV interactions in a safe and cost-effective manner. IVE can also allow for the inclusion of other road users such as cyclists and other drivers.

This study has several limitations. First, we conducted our study in IVE. It is possible that participants would react differently at actual crosswalks. Second, the AV behavior models were based on discrete states driven by the pedestrian's position. Finally, our crosswalk scenario involved only one human and a unidirectional street.

5 CONCLUSION

Autonomous vehicles are increasingly being deployed in our society leading to encounters with pedestrians. This study is an important start for studying the factors affecting trust in AV. Nonetheless, much more research is needed to build on these ideas and expand our understanding of trust between pedestrians and AVs.

ACKNOWLEDGMENTS

Toyota Research Institute (TRI) provided funds to assist the authors with their research but this article solely reflects the opinions and conclusions of its authors and not TRI or any other Toyota entity.

REFERENCES

[1] C. Basu and M. Singhal. 2016. Trust Dynamics in Human Autonomous Vehicle Interaction: A Review of Trust Models. In *2016 AAAI Spring Symposium Series*.
[2] L. A Baxter and B. M. Montgomery. 1996. *Relating: Dialogues and Dialectics*. Guilford Press.
[3] J. Blascovich, J. Loomis, A. C. Beall, K. R. Swinth, C. L. Hoyt, and J. N. Bailenson. 2002. Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry* 13, 2 (2002), 103–124.
[4] J. A. Colquitt, J. A. LePine, R. F. Piccolo, C. P. Zapata, and B. L. Rich. 2012. Explaining the justice–performance relationship: Trust as exchange deepener or trust as uncertainty reducer? *Journal of Applied Psychology* 97, 1 (2012), 1.
[5] Virtuix Inc. 2017. Virtuix Omni Platform. http://www.virtuix.com/product/omni-platform/. (2017). Retrieved: 2017-09-20.
[6] M. W. Kramer. 1999. Motivation to reduce uncertainty: A reconceptualization of uncertainty reduction theory. *Management Communication Quarterly* 13, 2 (1999), 305–316.
[7] T. Lagstrom and V. M. Lundgren. 2015. *AVIP-Autonomous vehicles interaction with pedestrians*. Master's thesis. Chalmers University of Technology, Gothenborg, Sweden.
[8] B. M. Muir. 1987. Trust between humans and machines, and the design of decision aids. *International Journal of Man-Machine Studies* 27(5-6) (1987), 527–539.
[9] Luke Petersen, Dawn Tilbury, and Lionel Robert. 2017. Effects of Augmented Situational Awareness on Drive Trust in Semi-autonomous Vehicle Operation. *Presented at the Autonomous Ground Systems Technical Session of the Ground Vehicle Systems Engineering and Technology Symposium* (2017). http://hdl.handle.net/2027.42/137707
[10] D. Rothenbücher, J. Li, D. Sirkin, B. Mok, and W. Ju. 2016. Ghost driver: A field study investigating the interaction between pedestrians and driverless vehicles. In *Robot and Human Interactive Communication (RO-MAN), 2016 25th IEEE International Symposium on*. IEEE, 795–802.