Will Passengers Trust Driverless Vehicles?

Removing the steering wheel and pedals

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Abstract— Driverless passenger vehicles are an emerging technology and a near-term eventuality. As such, the role of someone onboard the vehicle will change from the active role of a driver to the passive role of a passenger. The goal of this work is to provide an initial assessment of this interaction, with a specific focus on the impact of different available control interfaces on trust, usability, and performance. Participants interacted with two simulated driverless passenger vehicles that were designed to mirror a real-world prototype vehicle for Soldier transit on a U.S. military installation. Vehicle 1 had a traditional wheel and pedal control interface, as well as two buttons to disengage or re-engage the vehicle's automation system. Vehicle 2 only had the button system available with which to disengage the automation and bring the vehicle to a safe stop in the simulation and then re-engage. Both vehicles were designed to function optimally throughout the virtual environment. Findings suggested equal trust and usability ratings between the two vehicles. However, participants tended to intervene more often with the traditional control interface. Individual differences and preference ratings are reported.

Keywords—*ARIBO, driverless vehicle, human-robot interaction, trust*

I. INTRODUCTION

With the continued push to advance safety in passenger vehicles, the design, development, and integration of vehicle automation has become an active area of research and implementation. There are two schools of thought that are emerging in the industry sector of vehicle safety automation. On one side, vehicle design is focused on the development of automated, or preprogrammed, systems that help to augment the driver's capabilities¹. Systems such as cruise control, parking aids, and advanced warning systems assist the driver, but still allow the driver to maintain active control. On the other side, the focus has transitioned toward research and development of prototype autonomous driverless passenger

vehicles, where the control of the driving is primarily the responsibility of the vehicle.

Driverless vehicles have the potential to increase efficiency, improve safety, reduce traffic congestions, and even increase resource utilization by enabling new car sharing models [2]. In addition, there are a number of benefits for use of this technology for individuals who are not capable of driving such as the injured or the elderly, and in areas with limited public transportation. Yet despite the many potential benefits of this technology, many believe the major factor limiting wide-spread acceptance of autonomous, driverless vehicles will not be technical in nature but the humans who interact with the technology [3-5]. Cultural and societal limits such as well-intentioned but restrictive rules and regulations; litigation that threatens or shuts down innovative companies; individuals refusing to accommodate certain changes to their habits or norms; or a general fear of giving up control may be what limits the introduction and widespread use of autonomy-enabled vehicles [6-8]. As such, until trust is established, the vehicle has the potential to be underutilized, misused, or even unused (see [9]). Thus, knowledge about human behavior and the social sciences can be used to design better systems and interfaces between these vehicles and the people using them [10].

A. ARIBO

One research effort looking at advancing the technical capabilities of driverless vehicles, as well as integrating the human user into the design process, is the Applied Robotics for Installation and Base Operations (ARIBO) project by the US Army Tank Automotive Research Development and Engineering Center. ARIBO is designed as a series of pilot projects to coordinate technology development and on-base operational needs and accelerate the adoption of autonomous vehicle technologies [11]. In these pilots, users and non-users continuously interact with the technologies in a real-world, dynamic setting. The primary advantage of using *operational* military installations is access to semi-controlled and well-defined, traffic environments combined with the flexibility to modify various elements of the physical infrastructure, via the base's chain of command [12]. In this environment, interactions between people and the autonomous vehicles can be observed in a naturalistic setting. Installation road networks

¹ The National Highway Traffic Safety Administration [1], estimated that in a two year time period there were over two million vehicle accidents nationwide involving over four million vehicles. Of these accidents, the critical reason for these accidents were primarily due to human error ($\approx 94\%$) including recognition errors, decision errors, and performance errors.

include both urban and rural settings with high-speed separated lanes, signaled intersections, four-way stops, parking lots and pedestrian traffic. These similarities suggest findings from installations will be generalizable to other traffic situations.

The Ft. Bragg, NC, ARIBO pilot project provides opportunities for research including comparative analysis between human decisions and autonomy, operational efficiency impact, user and non-user behavior, trust, acceptance, and vehicle platform and technology maintenance and reliability. Technology and system architecture are being leveraged from other TARDEC autonomous vehicle projects that directly support the Army's warfighting mission. Within the scope of this particular pilot project, a real-world driverless vehicle is being developed to provide on-demand transportation to Soldiers traveling between the Warrior Transition Battalion (WTB) barracks and the Womack Army Medical Center (WAMC). These frequent, short-distance door-to-door trips between living quarters and appointments at the medical center² provide an environment to better understand the systemic impacts of driverless vehicle integration (see Fig. 1).

Fig. 1. Illustrative example of vehicle routes at Ft. Bragg, NC.

The ARIBO vehicle(s) will be introduced using a phased introduction of autonomous control of the type planned should ensure safe operations and a smooth increase in trust and confidence of the system. Phase I begins with human-operated shuttle service, transitioning to Phase II which is autonomous operation with an on-board safety operator ready to take over in the event of an emergency. Phase III is fully driverless vehicle operations with no on-board safety operator. A monitor station will provide supervisory control of the driverless vehicles. Functionally, the service will provide a convenient mode of transportation and an opportunity to increase on-time appointment rate³. Scheduling interfaces for riders and fleet management software will accompany autonomous vehicle deployment with the objective to increase on-time appointment rates and mobility for individuals with physical and cognitive

² The distance along the designated route between the WTB barracks and WAMC is about 1/3 mile and negotiates mixed use pedestrian sidewalks, crosses a four-lane divided road around WAMC, negotiates a congested parking lot, and traffic circle at the WAMC main entrance.

³ Missed appointments account for about \$1.2M in annual cost

disabilities. Operational statistics, such as system maintenance and reliability data, combined with research findings involving user trust and non-user impact, will enable data-driven policy decisions.

B. Current Work

As the prototype vehicles are yet to be put into service, a computer-based simulation was built to reflect the physical environment, vehicle system requirements, and anticipated vehicle behaviors. The design is in line with the goals of the ARIBO project for alternative transportation options for non-emergency wounded Soldier transit at Ft. Bragg, N.C. The scope of the current work is aimed at quantifying the level of trust of a person onboard a driverless vehicle, and the relationship of that trust level to the design of vehicle control systems.

1) *Trust Theory*: The theoretical foundation for this study was based on the Three Factor Descriptive Model of Human-Robot Trust (first identified by Hancock et al. [13], and later updated by Schaefer et al. [14]). This meta-analytic work identified the important antecedents of trust related to the human, the robot (or autonomy-enabled systems), and the environment. Fig. 2 identifies the antecedents of trust and shows the interdependent relationship between the human, robot, and environmental factors.

Note. *The items listed as cognitive factors include additional antecedents of trust: ease of learning, prior experiences, self-efficacy, workload, expertise, familiarity, and proximity. ^bThe antecedents of trust with the team collaboration category include role interdependence, team composition, mental models, cultural and societal impact, and in-group membership.

Fig. 2. Venn diagram showing the interdependent nature of trust across the three factors of trust (adapted from Schaefer et al. [14].)

All items listed in this figure have theoretical or empirical support for being included in the model. The model has incorporated research from a number of robotic and automation

domains including various types of driver-based automation systems. This descriptive model was found to be relevant to the specific driverless vehicle application, per our prior studies [15], [16].

2) *Trust and Control Allocation*: As the vehicle's level of autonomy advances, more control should be allocated to the vehicle for tasking related to movement, obstacle avoidance, path planning, etc. The role of the person on-board the vehicle will transition during this process from an active driver to a safety rider monitoring the vehicle and environment, and eventually to the passive role of a passenger. Thus, the need for direct control systems like the steering wheel and pedals should be less. For example, early designs of civilian driverless vehicles (e.g., Google car) have proposed removing the traditional control systems (e.g., steering wheel and pedals) from the vehicle [17].

The topic of design specific control allocation is important for driverless vehicle applications. For example, findings from the first study in this series [15], showed that individuals fulfilling the role of a safety rider will either intervene in the autonomous control allocation settings (e.g., change speed allocation) or take over full manual control, even when the vehicle is functioning at an optimal level. Banks et al. [18] contend that automated vehicles operating in a supervised mode actually increase the number of driving processes for which a human is responsible, increasing the complexity of the driving process. Therefore, limiting the number of control options available to the user may reduce feelings of responsibility specific to the control the vehicle, as well as reduce the number of inappropriate interventions that could reduce the safety of the vehicle. However, limiting the capability to intervene in the vehicle's functional capability may affect the passenger's trust perception of the vehicle. Thus, to better understand this type of human-vehicle interaction, as well as the potential outcomes of these interactions, we ask the following research question: Does the type of available control system (i.e., steering and speed control vs. disengage/re-engage buttons) impact trust, usability, and performance?

II. METHODS

A. Participants

Twenty participants were recruited from the local Army Research Laboratory population (14 male, 6 female). All participants were between the ages of 18 and 64, and had a valid driver's license. The average years of experience driving was 23.75 years ($SD=11.285$).

B. Computer-based Simulation: RIVET and CARVE

This study used the Robotic Interactive Visualization and Experimentation Technology (RIVET) simulation software developed by General Dynamics Robotics System for the US Army Research Laboratory's Robotics Collaborative Technology Alliance [19]. RIVET uses an adapted Torque Game Engine development and runtime environment with a

client/server networking model. It was used to create the virtual environment, mission space, and all environmental constraints (e.g., pedestrians, other vehicles, weather, etc.). The CARVE (Control of Autonomous Robotic Vehicle Experiments) application developed by the US Army Research Laboratory was used in conjunction with RIVET to set and control the autonomous capabilities of the vehicle within the virtual environment (e.g., path, movement, speed control, and options to disengage/re-engage the vehicle automation system). CARVE was also used to record all inputs from the participants (e.g., time in autonomous control mode, total run time, frequency of interactions, etc.). This simulation system has been used to identify trust-based difference during human-robot interaction experiments [16], [20], and has been found to accurately represent real-world interactions [21].

C. Equipment: System Controls

Participants interacted with two simulated driverless vehicles using external system controls. Participants had access to a red (disengage) and a green (re-engage) button for both simulated vehicles. Buttons were 50.8 mm in diameter and 63.5 mm apart. They were housed in a Styrofoam box and could be moved for either left or right-handed preference. One of the simulated vehicles (Vehicle 1) included a Logitech G27™ steering wheel and control pedals (see Figure 3). Participants could disengage the vehicle's automation system by pressing the red disengage button, by interacting with the steering wheel, or by depressing either of the pedals.

Fig. 3. System control set-up.

D. Materials

Trust, antecedents of trust, and performance, as well as usability and preferences were assessed.

a) *Trust*: Trust was measured as a trait (Interpersonal Trust Scale - ITS [22]), and as a state, pre- and post-interaction (Trust Perception Scale-HRI [20], [23]).

b) *Antecedents of Trust*: Multiple subjective scales were used to assess possible antecedents of trust described in the Three Factor Descriptive Model of Trust [13] [14].

- *Personality Inventory*: The Mini-IPIP scale personality assessment [24] is a short form of the International Personality Item Pool – Five Factor Model [25] used to measure: agreeableness, extraversion, intellect, conscientiousness, and neuroticism.
- *Workload*: The NASA-Task Load Index provides workload assessment specific to mental demand, physical demand, temporal demand, performance, effort, and frustration [26].
- *Demographics*: An author-created questionnaire was created to assess gender, ethnicity, and experience with driving, research, robotics, and automation.

c) *Usability and Technology Preferences*: The System Usability Scale (SUS) was used to differentiate between usable and unusable systems [27]. In addition, an author-created System Preferences Questionnaire assessed participants' self-reported expectations and preferences for the design of each vehicle.

d) *Performance*: Performance measurements included the time controlling the vehicle, frequency and duration of time adapting autonomous behaviors (e.g., steering, braking, disengaging/re-engaging autonomous control), and frequency for each type of intervention.

E. Procedure

Prior to arriving at the study location, participants provided informed consent and completed the ITS, Mini-IPIP, and Demographics Questionnaire. Upon arrival at the study location, participants reviewed informed consent, completed pre-interaction surveys (Trust Perception Scale-HRI; NASA-TLX). Participants then had an opportunity to become familiar with the equipment, including the virtual environment (VE), simulated vehicle, and system controls. Following the practice session, participants were instructed that they would be a passenger onboard two different vehicles that would pick-up and drop-off three different wounded Soldiers at various locations in the VE. Both vehicles could function completely autonomously; however, participants were instructed that they could intervene if they felt it was necessary for the safety of themselves, other passengers, or pedestrians. Interventions with the vehicle were collected through a data collection system programmed within CARVE for each vehicle. Participants completed the Trust Perception Scale-HRI, NASA-TLX, SUS, and System Preferences Questionnaire after interacting with each vehicle. Participants were also asked to provide preferences for a user feedback system that would help to engender trust in the real-world vehicle.

III. RESULTS

All data were analyzed using IBM SPSS Statistics Software, v.22 [28]. These results compare *Vehicle 1* (with traditional wheel and pedal controls) and *Vehicle 2* (without traditional controls), in terms of trust, usability, and performance. As stated previously, participants interacted with both vehicles and had access to the disengage/re-engage buttons for both. The simulated vehicles were designed to

function reliably and appropriately for navigation, movement, and obstacle detection and avoidance. The order was counterbalanced, and no ordering effects were detected.

A. Trust

A Pearson correlation coefficient was computed to determine the relationship of trust between *Vehicle 1* and *Vehicle 2*. Overall the correlation was significant, $r(18) = 0.94$, $p < .001$. A paired-samples *t*-tests was then conducted to evaluate the mean differences trust between the two vehicles. The results indicated that the mean subjective trust score for *Vehicle 1* ($M = 72.15\%$, $SD = 17.62$) was not significantly different from *Vehicle 2* ($M = 70.66\%$, $SD = 18.02$), $t(19) = 1.04$, $p = .312$ (Fig. 4).

Fig. 4. Trust scores (%) and confidence intervals for each vehicle.

Findings suggest that when the simulated vehicles function optimally, people tend to trust both vehicles equally. However, the large standard deviations suggest some variability among individuals trust scores. Additional analyses were conducted to understand the possible relationship between individual differences and trust scores that may account for some of this variability. Pearson correlation coefficients were calculated to determine if any of the previously defined antecedents of trust were related to trust of either of the vehicles. The results of the significant correlational analyses between trust and individual differences for both *Vehicle 1* and *Vehicle 2* are presented in Table 1.

TABLE I. SIGNIFICANT PEARSON CORRELATIONS

	Vehicle 1 Trust	Vehicle 2 Trust
1.Pre-Trust	$r(18) = 0.49, p = .028$	<i>n.s.</i>
2.Gender	$r(18) = -0.48, p = .013$	$r(18) = -0.49, p = .027$
3.Extraversion	$r(18) = -0.47, p = .036$	<i>n.s.</i>
4.Intellect	$r(18) = 0.56, p = .010$	$r(18) = 0.67, p = .001$
5.Performance*	<i>n.s.</i>	$r(18) = 0.53, p = .014$
6. Frustration*	<i>n.s.</i>	$r(18) = -0.62, p = .004$

Note. The * denotes that these scores were weighted workload scores.

Trust was measured prior to any interaction with the simulated vehicles providing a measurement based on the individual's expectations of the interaction, and then following the interaction with each of the two vehicles. The finding of a

positive significant correlation only with *Vehicle 1* (Table 1, Row 1) suggests that interaction experiences that align more closely to individual preconceptions of the driving experience engender greater trust in the vehicle.

The second finding of note was that the weighted scores from the NASA TLX workload survey for the subscales for performance and frustration were significantly correlated with *Vehicle 2* only. Thus, higher performance was related to higher trust, and higher frustration ratings were related to lower trust (Table 1, Rows 5 and 6). This suggests that perceived workload may indeed be an important factor to consider when considering changing user controls for a driverless vehicle. More research should be conducted in this area.

The third major finding was related to the relationships between gender and trust in both vehicles (Table 1, Row 2). A one-way analysis of variance was conducted to evaluate the relationship between gender and trust for each vehicle. The ANOVA for *Vehicle 1* was significant, $F(1,18) = 5.50$, $p = .031$, $\eta^2 = .234$. Males ($M = 77.59$, $SD = 15.478$) trusted *Vehicle 1* more than females ($M = 59.46$, $SD = 16.773$). Similarly, the ANOVA for *Vehicle 2* was also significant, $F(1,18) = 5.76$, $p = .027$, $\eta^2 = .242$. Males ($M = 76.32$, $SD = 14.693$) trusted *Vehicle 2* more than females ($M = 57.46$, $SD = 19.323$).

Additional analyses were also conducted for the personality trait of intellect (as measured by the Mini-IPIP). A one-way analysis of variance was conducted to evaluate the relationship between intellect and trust in *Vehicle 1*. The ANOVA was significant, $F(1, 18) = 8.59$, $p = .001$, $\eta^2 = .834$. A second ANOVA was conducted to evaluate the relationship between intellect and trust in *Vehicle 2*. This finding was also significant, $F(1, 18) = 11.29$, $p < .001$, $\eta^2 = .868$.

These findings suggest that gender, as well as intellect may explain some of the variance in the trust scores and thus should be explored in more depth in an additional study. However, it still holds true that overall there were nonsignificant mean differences in trust between the two vehicles overall (as illustrated in Fig. 4).

B. Usability

The next set of results explored the usability of *Vehicle 1* compared to *Vehicle 2*. Pearson correlation coefficients were computed among the usability of *Vehicle 1* and *Vehicle 2* were significant, $r(18) = 0.81$, $p < .001$. A paired-samples t -tests was then conducted. The results also indicated that the mean usability score for *Vehicle 1* ($M = 85.25$, $SD = 12.16$) was not significantly different from *Vehicle 2* ($M = 85.13$, $SD = 15.84$), $t(19) = 0.06$, $p = .953$. Findings suggest that participants felt that the design of both vehicles were equally usable (Fig. 5).

Additional Pearson correlations were conducted to assess the relationship between trust and vehicle usability. A positive, significant correlation was found for *Vehicle 1*, $r(18) = 0.52$, $p = .020$; and for *Vehicle 2*, $r(18) = 0.66$, $p = .002$. Findings suggest that the higher the trust in a vehicle, the more usable it is rated.

Fig. 5. Usability scores (SUS) with confidence intervals for each vehicle.

C. Performance

Multiple paired-samples t -tests were conducted to evaluate the mean differences in the total number of times the automation was disengaged and the number of red button presses between the two vehicles. There was not a significant difference in the total number of interventions for *Vehicle 1* ($M = 3.60$, $SD = 5.707$) and *Vehicle 2* ($M = 1.90$, $SD = 2.614$) conditions; $t(19) = 1.82$, $p = .084$. However, when each run was broken down into the three legs of the trip, there was a significant difference in the number of total interventions during the first leg of the trip for *Vehicle 1* ($M = 1.5$, $SD = 1.906$) and *Vehicle 2* ($M = 0.60$, $SD = .754$) conditions, $t(19) = 2.13$, $p = .046$. These findings suggest that participants disengage the vehicle autonomy more frequently for *Vehicle 1*. In addition, when comparing the method used to disengage the automation system, participants used the red button significantly less often for *Vehicle 1* ($M = 0.45$, $SD = .887$) than *Vehicle 2* ($M = 1.90$, $SD = 2.614$), $t(19) = 2.59$, $p = 0.018$. This suggests that when given the opportunity to interact with a vehicle equipped with traditional controls (i.e. steering wheel and pedal control systems), people tend to revert to using the familiar system.

D. Preference

Preferences were assessed using open-ended questions. The most interesting outcome was that all 20 participants reported there were times during the experiment that they thought about intervening, even if they did not intervene. Five individuals stated they felt the need to only intervene with *Vehicle 2*; five other individuals only felt the need to intervene with *Vehicle 1*. The remaining 10 participants stated they felt the need to intervene with both vehicles on at least one occasion. The primary reason for feeling the need to intervene in both vehicles was the safety of pedestrians. This was due to the lack of feedback to let the passenger know that the pedestrian was identified or the vehicle's intention to stop. In most of these instances, the participant waited to see if the vehicle would respond appropriately and refrained from intervening in the system's automation.

The second major finding from the preferences questionnaire was that there were mixed preferences between the two vehicles. Seven participants preferred *Vehicle 1* for reasons relating to feeling of control, realistic control, and the capability to intervene in case of failure. The remaining 13

participants preferred *Vehicle 2* stating they did not encounter instances where extra controls were necessary; less responsibility for the vehicle; and less mental load. However, a majority of participants who preferred the vehicle without the traditional controls stated that they would like full controls, or, at a minimum, a means to call for assistance in case of automation failure.

Finally, participants were asked to identify types of vehicle feedback or alerts that would assist a passenger on the real-world vehicle to engender trust in a driverless passenger vehicle. Four major areas were discussed: navigation, proximity information, system state, and passenger safety. *Navigation-related feedback* was by far the most recommended as the passenger wanted to know where they were located and the intended path. *Proximity-related information* was specific to obstacle detection and avoidance. Passengers wanted to confirm that the vehicle was aware of a potential obstacle and make the correct safety response. Items related to the vehicle's *system state* were regarding the overall vehicle health to make sure it was able to safely transport passengers. Finally, *passenger safety* was related to feedback that could affect the well-being of the passenger while onboard the vehicle (e.g., indication that the vehicle was aware that the passenger was seated before moving). Overall, the primary sentiment was that a better shared situation awareness (i.e., the capability to confirm that the vehicle is aware of the physical environment and intends to respond appropriately) will engender trust.

IV. DISCUSSION

One key debate for the design of driverless vehicles is related to the desired and required control interface that is located onboard the vehicle. More specifically, should the vehicle retain the traditional steering wheel and pedal controls, or is an alternative control interface an appropriate or better option? While at this time safety may dictate the need for the traditional control interface, this may not be an ideal method of interaction in all cases. For example, in this study's operational use case (wounded Soldier transit), passengers may not have the means to operate traditional vehicle controls.

This study does not provide a definitive and final answer on control interface design, but it does provide an introduction to understanding trust, usability, and performance outcomes that occur while interacting with two different simulated driverless vehicles (i.e., one with traditional controls and one without traditional controls). User preferences and performance data provide additional insights into the decisions related to control interface design for future driverless vehicles. This study underscores, not only the need to properly configure the human-robot interface(s), but the importance of user expectations.

To begin, results from this study marked the importance of expectations and familiarity on trust development in driverless vehicle technology. Driverless vehicles that have the same controls as traditional vehicles provide some degree of comfort and initial trust in the vehicle. That being said, participants had

a tendency to intervene more often when they had access to traditional controls. However, in cases where passengers were unable to superimpose their own driving preferences (i.e. no steering wheel or pedals were available), they were more likely to allow the vehicle to continue driving instead of intervening by pressing the red button and bringing the vehicle to a safe stop. This is an important issue as driverless vehicles begin to penetrate everyday society and policymakers wrestle with rules and manufacturers choose their technology investment priorities. There is a well-known axiom that says *90% of drivers believe they are above average*. Even a majority who preferred the vehicle without the traditional controls want to have them available for possible unknown and uncertain situations. However, people intervening in systems designed to operate autonomously introduce greater complexity and more risk

Despite the performance and preference differences, no significant difference in subjective trust ratings were found. On the surface this is not too surprising as the functional capabilities between the two vehicles were consistent and reliable. However, the mean scores (trust scores in the low-70s for both vehicles) seem unusually low for a simulation designed to operate perfectly. Two things may explain the lower scores. We know from the Three Factor Model of Human-Robot Trust [13], [14] that factors other than vehicle reliability impact trust, namely factors related to environmental risk and feedback. The driving environment for our simulation was built to have a high perceived level of risk. There were pedestrians, other vehicles, and obstacles in close proximity to the vehicle. It was set up so that *if there were* indeed an error in the vehicle's autonomous functionality, an accident could occur. In addition, the vehicles were not designed to provide any feedback or information to the passenger. While we purposely designed the simulation without feedback to create a baseline for the future work, it is important to note that appropriate communication has been shown to be incredibly important to trust development and the development of shared situation awareness [14].

User design recommendations identified four areas of vehicle feedback or alerts that could be used to develop a shared situation awareness to engender trust in the vehicle despite the available control interface. These included feedback related to vehicle navigation, proximity information, system state, and passenger safety. For example, one of the primary reasons participants gave for wanting to intervene in the automation was concern over striking a pedestrian. Participants were uncomfortable because they were unsure if the vehicle detected the pedestrian, thus they did not have a shared understanding of the driving environment. They did not express concern that the pedestrian was not alerted or notified that the vehicle had detected them.

In addition, this study lays the groundwork for future research that further explores the trust gap between the two vehicle configurations. One additional question of interest for this application area is: How is trust in the two vehicle configurations different for users who cannot physically

intervene via traditional means (steering wheel and pedals)? In addition, this experiment used simulations in which the vehicle was programmed to run perfectly. While this created an excellent baseline for trust calibration, more work is needed to explore how trust is impacted when vehicles operate less than optimally or when communications fail. Therefore future research should systematically assess the effects of the four types of recommended vehicle feedback on trust development.

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REFERENCES

- [1] National Highway Traffic Safety Administration (2015). Critical reasons for crashes investigated in the national motor vehicle crash causation survey (DOT HS 812 115). NHTSA's National Center for Statistics and Analysis: Washington, DC. <http://www-nrd.nhtsa.dot.gov/pubs/812115.pdf>
- [2] S. Thrun, "Toward robotic cars," *Communications of the ACM*, vol. 53, no. 4, pp. 99-106, 2010.
- [3] C. Alvarez. (2014 Feb 03). *Study finds 88 percent of adults would be worried about riding in a driverless car* [Online]. Available: <http://www.seapine.com/about-us/press-release-full?press=217&title=study-finds-88-percent-of-adults-would-be-worried-about-riding-in-a-driverless-car>
- [4] M. Richtel and C. Dougherty. (2015 Sept 01). *Google's driverless cars run into problem: Cars with drivers* [Online]. Available: http://www.nytimes.com/2015/09/02/technology/personaltech/google-says-its-not-the-driverless-cars-fault-its-other-drivers.html?_r=0
- [5] K. Leswing (2014 Dec 06). *Driverless cars need to make their passengers feel like drivers* [Online]. Available: <https://gigaom.com/2014/11/18/driverless-cars-need-to-make-their-passengers-feel-like-drivers/>
- [6] R. Calo, "Open Robotics," *Maryland Law Review*, vol. 70, no. 3, 2011.
- [7] Degroat, "Self-driving vehicles generate enthusiasm, concerns worldwide," *PhysOrg*, 31 October 2014. [Online]. Available: <http://phys.org/news/2014-10-self-driving-vehicles-enthusiasm-worldwide.html>. [Accessed 8 November 2014].
- [8] D. Z. Morris, "Trains and self-driving cars, headed for a (political) collision," *Fortune*, 2 November 2014. [Online]. Available: <http://fortune.com/2014/11/02/trains-autonomous-vehicles-politics/>. [Accessed 8 November 2014].
- [9] B. Lussier, M. Gallien, J. Guiochet, F. Ingrand, M. Killigian, and D. Powell, "Fault tolerant planning for critical robots," in *IEEE International Conference on Dependable Systems and Networks*, Edinburgh, 2007, pp.144-153.
- [10] A. Heide and K. Henning, "The 'cognitive car': A roadmap for research issues in the automotive sector," *Annual Reviews in Control*, vol. 30, no. 2, pp. 197-203, 2006.
- [11] P. Marshall. (2014). *Army tests driverless vehicles in 'living lab'* [Online]. GCN Technology, Tools and Tactics for Public Sector IT. Available: <http://gcn.com/articles/2014/07/16/aribo-army-tardec.aspx>
- [12] E. Straub, "The Impact of Autonomy-Enabled Vehicles and System Controls on Non-Users in Semi-Controlled Environments," in *NDIA Ground Vehicle Systems Engineering and Technology Symposium*, Novi, MI, 2015.
- [13] P. A. Hancock, D. R. Billings, K. E. Schaefer, J. Y. C. Chen, R. Parasuraman, and E. de Visser, "A meta-analysis of factors affecting trust in human-robot interaction," *Human Factors*, vol. 53, no. 5, pp. 517-527, 2011.
- [14] K. E. Schaefer, J. Y. C. Chen, J. L. Szalma, and P. A. Hancock, "A meta-analysis of factors influencing the development of trust in automation: Implication for understanding autonomy in future systems," *Human Factors*, in press, 2016.
- [15] K. E. Schaefer, and S. G. Hill, "Trust in robotic passenger vehicles: Dual-task engagement during base operations," U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, Tech. Rep., in press.
- [16] K. E. Schaefer, and D. R. Scribner, "Individual differences, trust, and vehicle autonomy: A pilot study," in *Human Factors and Ergonomics Society*, Los Angeles, CA, 2015, in press.
- [17] Newman, J. (2014). *Google's driverless car prototype will get a steering wheel after all* [Online]. TechHive. <http://www.techhive.com/article/2597645/googles-driverless-car-will-get-a-steering-wheel-after-all.html>
- [18] V. A. Banks, N. A. Stanton, and C. Harvey, "Sub-systems on the road to vehicle automation: Hands and feet free but not 'mind' free driving," *Safety Science*, vol. 62, pp. 505-514, 2014.
- [19] J. P. Gonzalez, W. Dodson, R. Dean, G. Kreaflle, A. Lacaze, L. Saponov, and M. Childers, "Using RIVET for parametric analysis of robotic systems," in *Ground Vehicle Systems Engineering and Technology Symposium*, Troy, MI, 2009.
- [20] K. E. Schaefer (2013). *The Perception and Measurement of Human-Robot Trust*. (Unpublished doctoral dissertation). University of Central Florida, Orlando, FL.
- [21] K. E. Schaefer, T. L. Sanders, T. A. Kessler, M. Dunfee, T. Wild, and P. A. Hancock, "Fidelity & validity in robotic simulation," in *IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support (CogSIMA)*, Orlando, FL, 2015, 113-117.
- [22] J. B. Rotter, "A new scale for the measurement of interpersonal trust," *Journal of Personality*, vol. 35, no. 4, pp. 651-665, 1967.
- [23] K. E. Schaefer, "Measuring trust in human robot interactions: Development of the 'Trust Perception Scale-HRI,'" in *The Intersection of Robust Intelligence (RI) and Trust in Autonomous Systems*, W. Lawless, R. Mittu, A. Wagner, and D. Sofge, Eds. Springer, in press.
- [24] M. B. Donnellan, F. L. Oswald, B. M. Baird, and R. E. Lucas, "The Mini-IPIP scales: Tiny-yet-effective measures of the Big Five factors of personality," *Psychological Assessment*, vol. 18, no. 2, pp. 192-203, 2006.
- [25] L. R. Goldberg, "A broad-bandwidth, public-domain, personality inventory measuring the lower-level facets of several five-factor models," in *Personality Psychology in Europe*, I. Mervielde, I. J. Deary, F. De Fruyt, and F. Ostendorf, Eds. Tilburg, The Netherlands: Tilburg University Press, Vol. 7, pp. 7-28, 1999.
- [26] S. G. Hart, & L. E. Staveland, "Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Human Mental Workload*, P. A. Hancock and N. Meshkati, Eds. Amsterdam: North Holland Press, pp. 139-183, 1988.
- [27] J. Brooke, "SUS: A 'quick and dirty' usability scale," in *Usability Evaluation in Industry*, P.W. Jordan, B. Thomas, I. McClelland, B. Weerdmeester, Eds. Bristol, PA USA: Taylor & Francis, 1996, pp. 189-194.
- [28] IBM Corp., "IBM SPSS Statistics for Windows, Version 22.0," Armonk, NY: IBM Corp., 2013.