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Trust in Autonomous Vehicles

The Case of Tesla Autopilot and Summon

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***Abstract*—Autonomous driving is on the horizon. Vehicles with partially automated driving capabilities are already in the market. Before the widespread adoption however, human factors issues regarding automated driving need to be addressed. One of the key issues is how much drivers trust in automated driving systems and how they calibrate their trust and reliance based on their experience. In this paper, we report the results of a survey conducted with Tesla drivers about their experiences with two advanced driver assistance systems, Autopilot and Summon. We found that drivers have high levels of trust in Autopilot and Summon. Trust decreased with age for Autopilot but not for Summon. Drivers who experienced unexpected behaviors from their vehicles reported lower levels of trust in Autopilot. Over time, trust in these systems increased regardless of experience. Additionally, trust was correlated with several attitudinal and behavioral factors such as frequency of use, self-rated knowledge about these systems, and ease of learning. These findings highlight the importance of trust in real world use of autonomous cars. Also, the results suggest that previous findings on trust in automation are applicable to real world cases as well.**

Keywords—trust in automation; automated driving; advanced driver assistance systems

I. Introduction

Vehicles with partially autonomous driving capabilities recently became available. Currently, tens of companies are involved in building advanced driving automation systems and self-driving cars [1]. Before these technologies become widespread, there is a need to understand how drivers will behave in partially automated vehicles, vehicles that require constant monitoring by the driver (Level 2 in SAE classification, [2]). A key element in understanding driver-automated vehicle relationship is identifying psychological characteristics of drivers and cognitive processes that influence how drivers use these technologies. One important component of these processes is trust in automation. This study aims to understand the role of trust in driver-vehicle interaction in the context of automated vehicles.

Tesla drivers have been enjoying advanced driver assistance systems for some time. In 2015, Tesla introduced two advanced driver assistant systems, Autopilot and Summon [3]. Autopilot is a combination of lane steering assistance and adaptive cruise control, allowing hands free driving in a limited context. Summon is an automated parking system which allows the vehicle to maneuver into and out of the garage using a smartphone app. Previously, we reported drivers' general attitudes towards these features, and how they use these systems [4]. The current study extends those findings by investigating Tesla drivers' trust in Autopilot and Summon.

Tesla's Autopilot system, along with other advanced driver assistance systems (ADAS) are far from being perfect and failures are common [4]. Given this imperfection, a critical issue is the degree of reliance on these automated systems. If drivers completely rely on the capabilities of these vehicles, negative consequences as a result of automation failures will be inevitable. An example is a recent fatal Tesla crash [5]. On the other hand, if drivers don't rely on these systems at all, the opportunity to save more lives thanks to automation being superior than human drivers under certain circumstances will be missed. An important concept, trust, can help us in understanding how appropriate reliance can occur. In this work, we will present findings of an online survey on Tesla drivers' trust and confidence in Autopilot and Summon.

II. Background

Trust has been a fundamental concept in human-automation interaction [6]–[8]. Inappropriate calibration of trust in an automated system can lead to misuse (overreliance) and disuse (underreliance) of automation [8] and result in decreased performance and less adoption. There has been considerable research on trust in automation (See [6], for a review; [9] for a meta-analysis on factors influencing trust). Lee and See [7] identified three factors that are critical in trusting an automated agent: performance, process, and purpose. Performance refers to operator's observation of results, process refers to operator's assessment of how the system works, and purpose refers to the intention of the system. These dimensions should match with each other in operator's mind to establish appropriate levels of trust. For example, if observed performance matches the operator's understanding of the system (process), then appropriate levels of trust can be developed.

Trust and reliance on automation increases as perceived reliability of the automation increases [10]–[12]. Trust seems to act as a precursor to reliance and mediate the relationship

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between beliefs and reliance [13], [14]. It decreases with automation error [15], [16], but providing explanations of why the error occurred (observing the process; [7]) can increase trust and reliance despite the errors [13]. Also, trust is more resilient when an automation error occurs if the operator has the ability to control and compensate for these errors [12]. In addition, the type of automation error influences trust and reliance differently [10]. For example, increased false alarm rates result in less reliance on automation while alarms that are accurate but not needed by drivers increase trust [17]. Trust in automation increases over time, especially if there are no major failures [18], and regardless of prior exposure to automation errors [19]. It can even increase over time without constant exposure to the automated system [20].

Age can also effect trust in automation. Older people tend to have higher levels of trust in automation [18], [21], [22]. Findings regarding how older people calibrate their trust in and reliance on automation are mixed. While some studies showed that they may use different trust calibration strategies [23], [24], others did not [21].

Taken together, these findings highlight the importance of trust in and reliance on automated systems. However, most of the findings discussed are based on laboratory studies and there is a lack of research in the real-world usage of autonomous cars. To fill this gap, we will present the results of a survey we conducted with Tesla drivers, asking about their attitudes towards Autopilot and Summon and their trust and confidence in these systems. Based on previous work, we expected trust to be related to frequency of use, increase over time, negatively affected by experiencing an automation failure, and increase with age.

III. Methodology

We conducted and online survey with Tesla drivers in April-May 2016 [4]. In the survey, we asked questions about their experiences with Autopilot and Summon systems, and their attitudes towards these systems. We reached to 162 Tesla drivers, of which 121 fully completed the survey. 94.2% were male, and 89.3% had 10 years or more driving experience. 90.1% of them had used Autopilot and 85.2% had used Summon before. Additionally, 62.4% of the drivers reported that they experienced an unexpected or unusual behavior from the car when using Autopilot and 21.2% when using Summon. The unexpected situations for Autopilot were mostly related to steering (e.g. failure to detect the lane, trying to move to other lanes) and speed (e.g. sudden acceleration or deceleration). Unexpected situations for Summon occurred mostly due to technical problems such as connection failures. [4].

In the survey, we asked participants to rate their trust in Autopilot and Summon on two 5-point Likert scale items measuring trust and confidence in Autopilot and Summon. We averaged these items and created a trust score. Similarly, we asked same questions for their initial trust and confidence and created an initial trust score by averaging these items. We also asked, on 5-point Likert scales, about frequency of use, knowledge about these systems, ease of learning, usefulness of the Autopilot display, an in-vehicle display showing graphical representation of the own-vehicle and other vehicles identified on the roadway, and perceived level of risk involved for those who have experienced an Autopilot or Summon incident. Additionally, we asked about their computer expertise on a 4-point Likert scale.

IV. Results

In the following analysis, we used data from Autopilot users (N = 109) for trust in Autopilot and data from Summon users (N = 99) for trust in Summon. We compared initial and current trust for Autopilot and Summon. We also examined the relationship between trust and other measures, as well as how experiencing an automation failure influences trust in Autopilot and Summon.

A. Trust in Autopilot

Overall, participants reported high levels of trust in Autopilot (M = 4.02, SD =.65) and moderate levels of initial trust (M = 2.83, SD = .82). As shown in Table 1, trust in Autopilot was positively correlated with frequency of Autopilot use, self-rated knowledge about Autopilot, ease of learning, and usefulness of Autopilot display. Surprisingly, for those who experienced an Autopilot incident (N = 68), trust was not correlated with how risky they perceived the situation. However, perceived risk was negatively correlated with frequency of use.

TABLE I. Correlations between trust in Autopilot and other variables. Knowledge refers to self-rated knowledge about how Autopilot makes decisions. Importance refers to perceived importance of knowing how Autopilot makes decisions. Usefulness refers to perceived usefulness of Autopilot display. Perceived risk is the level of risk involved in reported incidents.

	Variables	*Mean*	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	Initial Trust	2.83	.82									
2	Current Trust	4.02	.65	.44**								
3	Computer expertise	4.50	.66	.05	.11							
4	Frequency of Use	4.19	.65	.30**	.52**	.14						
5	Knowledge	3.79	.82	.34**	.26**	.28**	.25**					
6	Ease of learning	4.27	.72	.23*	.36**	.18	.29**	.19*				
7	Importance	3.51	1.08	.15	.06	.31**	.08	.38**	-.13			
8	Usefulness	4.06	.70	.20*	.40**	.10	.28**	.12	.22*	.21*		
9	Perceived risk	2.74	.87	-.15	-.09	.06	-.27*	.07	-.13	0.24	-.21	

* $p < .05$, ** $p < .01$.

Age was presented as a categorical question in this study, and covered ages from 16 to 65 and older. A one-way ANOVA showed a significant age effect on trust, $F(6, 102) = 2.63$, $p = .02$, partial $\eta^2 = .13$. A trend analysis was also significant, $F(1, 102) = 7.80$, $p = .006$. As shown in Fig. 1, trust in Autopilot slightly but significantly decreased with age.

Next, we compared Tesla drivers' initial and current trust in Autopilot and how experiencing an incident (Incident) or not (No Incident) affects trust. A 2x2 mixed ANOVA with time as a within-subjects factor (Initial Trust, Current Trust) and Autopilot incident as a between-subjects factor (Incident, No Incident) showed a main effect of time on trust, $F(1, 107) = 221.05$, $p < .001$, partial $\eta^2 = .67$, and a main effect of incident, $F(1, 107) = 9.59$, $p = .002$, partial $\eta^2 = .08$. The interaction effect was not significant, $p = .086$. As shown in Fig. 2, current trust was higher than initial trust, and those who experienced an Autopilot failure reported lower levels of trust. Surprisingly, they also reported lower levels of initial trust.

B. *Trust in Summon*

Participants ($N = 99$) reported high levels of trust in Summon ($M = 3.80$, $SD = .93$) and moderate levels of initial trust ($M = 3.11$, $SD = 1.01$), similar to Autopilot. As shown in Table 2, trust in Summon was positively correlated with self-rated knowledge about Summon, and ease of learning. Current trust was positively correlated with frequency of use, and initial trust was positively correlated with computer expertise. Both initial and current trust were positively correlated with knowledge about these systems and perceived ease of learning. For those who reported a Summon incident ($N = 21$), initial trust but not current trust was negatively associated with perceived risk of the situation. A one-way ANOVA showed no effects of age on current trust in Summon, $F(6, 92) = 1.78$, $p = .108$. Trust in Summon did not differ across age groups.

Fig. 2. Trust in Autopilot by age. Categories 16-20 and 21-24 had 4 and 2 participants, respectively. Error bars represent 95% confidence intervals.

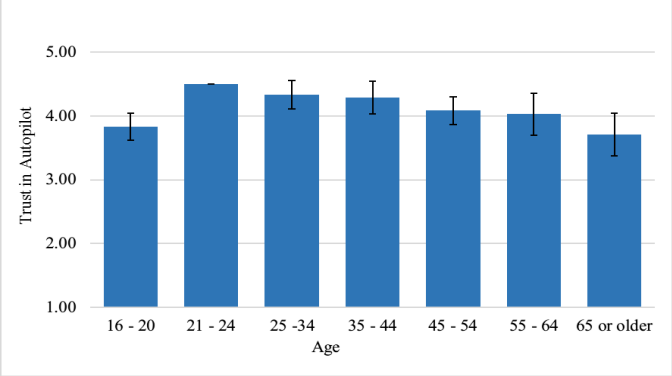


Fig. 1. Means of current and initial trust in Autopilot for Incident and No Incident groups.

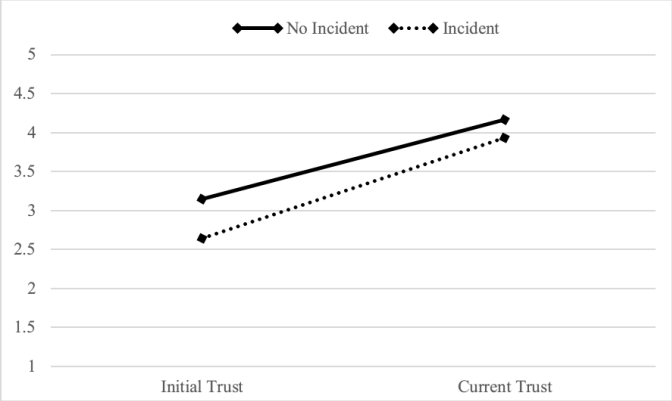
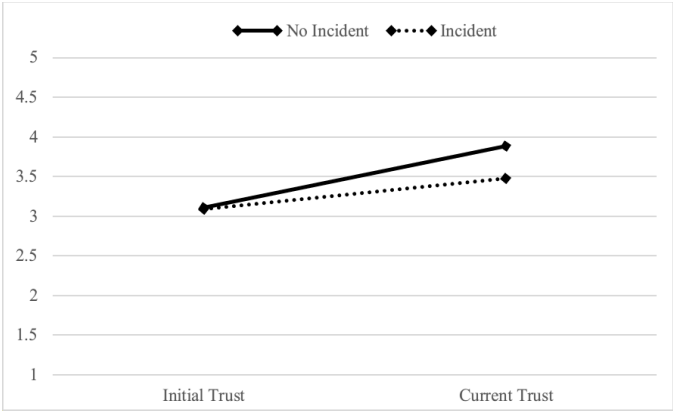


Fig 3. Means of current and initial trust in Summon for Incident and No Incident groups.



A 2x2 mixed ANOVA with time as a within-subjects factor (Initial Trust, Current Trust) and Summon incident as a between-subjects factor (Incident, No Incident) show a main effect of time on trust, $F(1, 97) = 23.52$, $p < .001$, partial $\eta^2 = .20$. Current trust in Summon was higher than initial trust (Figure 2). The main effect of incident was not significant, $F(1, 97) = 1.05$, $p = .309$; the interaction was not significant as well, $F(1, 97) = 2.74$, $p = .101$. Means are shown in Fig 3.

V. Discussion

In this work, our goal was to identify how Tesla drivers' trust in Autopilot and Summon relate to attitudes towards these systems, and how experience shapes their trust in these systems. Overall, we observed high levels of trust and moderate levels of initial trust. Trust increased over time regardless of whether participants experienced an automation failure. Trust in Autopilot but not Summon decreased as the age increased.

High levels of trust reported for both Autopilot and Summon indicate that the drivers are confident in these systems which is in line with previous findings [4]. Analysis of correlations revealed interesting patterns. Frequency of use of Autopilot was associated with trust. As expected, those who have higher levels of trust tend to use the system more often [13]. However, the reverse is also true: The more drivers experience Autopilot and Summon under different circumstances, the more their trust increases, which supports previous findings on the relationship between trust and experience [18], [19]. Ease of learning was also positively correlated with trust in Autopilot and Summon. The design features of automation such as usability influence trust by altering perceptions of users [6]. Likewise, easy to learn characteristics of Autopilot and Summon may have created perceptions of trustworthiness by making the adaptation

TABLE II. CORRELATIONS BETWEEN TRUST IN SUMMON AND OTHER VARIABLES. KNOWLEDGE REFERS TO SELF-RATED KNOWLEDGE ABOUT HOW SUMMON MAKES DECISIONS. IMPORTANCE REFERS TO PERCEIVED IMPORTANCE OF KNOWING HOW SUMMON MAKES DECISIONS. PERCEIVED RISK IS THE LEVEL OF RISK INVOLVED IN REPORTED INCIDENTS.

	Variables	*Mean*	*SD*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	Initial Trust	3.11	1.01								
2	Current Trust	3.80	.93	.49**							
3	Computer expertise	4.47	.68	.20*	.03						
4	Frequency of Use	2.67	1.08	.19	.22*	-.14					
5	Knowledge	3.56	.92	.31**	.32**	.18	.18				
6	Ease of Learning	3.99	.84	.35**	.45**	.12	.14	.36**			
7	Importance	3.11	1.17	.10	-.09	.27**	.001	.26**	-.02		
8	Perceived risk	2.14	1.24	-.49*	-.28	-.30	.30	.02	-.19	-.02	

* $p < .05$, ** $p < .01$.

smooth. The usefulness of Autopilot display was also positively correlated with trust in Autopilot. The main purpose of the Autopilot display is to show the sensing capabilities of the system to the user. At any time during the ride with Autopilot, drivers can glance at this display and see how Autopilot perceives other vehicles on the roadway and whether sensors become active (e.g. proximity sensors). In other words, this display enables the users to observe the process of automation [7]. If this transparency has a positive effect on trust, it can be an important part of adoption process for autonomous vehicles. However, as Lee and See [7] notes, having an appropriate level of trust is much more important than just higher levels of trust. While providing transparency can result in better trust calibration [25], further research is needed to identify how these drivers use the Autopilot display. Lastly, self-rated knowledge about how Autopilot or Summon makes decisions was positively correlated with trust in Autopilot and Summon, respectively. In general, knowledge about how these systems work, including their limitations, should result in appropriate trust calibration. However, we don't know the extent to which "self-rated knowledge" matches the accurate, objective knowledge about how these technologies work. Still, knowledge about how automation makes decisions, especially when it fails, can result in higher levels of trust [13]. Similarly, awareness of how Autopilot and Summon handles or fail to handle various situations might have resulted in appreciation of these technologies, and subsequently higher levels of trust. However, it is also possible that those who have a priori trust in these systems might be more willing to learn more about how the technology works behind the scenes, and improve their knowledge about the system. Further research is needed to establish how knowledge and mental models, both subjective and objective, relate to trust in autonomous vehicles.

Older people reported slightly lower levels of trust in Autopilot. This finding contrasts with previous research (e.g. [21]) which showed that older adults have higher levels of trust in automation than younger adults. One explanation for current findings is that older people tend to have more driving experience than younger drivers, and domain expertise has been shown to influence trust and reliance in automated decision aids. For example, farmers (domain experts) rely less on automated aids than non-farmers (domain novices) [10].

Another explanation might be the differences in risk perception. Younger drivers tend to perceive situations such as curved roads and rural environments less risky than older drivers [26]. It is possible that the perceived risk associated with automated driving might be different across different age groups. Nevertheless, we echo with Schaefer et al. [9] that there is a need for further research in understanding the relationship between age and trust in automation.

In terms of trust over time, we observed similar results for Autopilot and Summon. Trust increased over time for both Autopilot and Summon. This finding is consistent with previous work [18]–[20]. As drivers use these systems more, they likely become more comfortable. Over time, drivers may have adapted to this new environment, whereby they learned how to cooperate with an automated agent. Failures can be a challenge, but they can also provide a learning opportunity.

For Autopilot, those who experienced an incident reported lower levels of both current trust and initial trust. It was surprising to observe the differences between Incident and No Incident groups in initial trust in Autopilot. It is possible that those who experienced an Autopilot incident may have been subject to cognitive biases such as hindsight bias [27] and they may have responded based on their negative experiences. However, given other findings, we believe that a more likely reason is that these drivers might indeed have lower levels of trust in Autopilot at first, and this might have led them to be more sensitive to the capabilities of Autopilot. These drivers may be (a) more likely to consider certain situations as a failure, and (b) more motivated to explore the limits and capabilities of Autopilot to calibrate their trust better. They may, for example, have used Autopilot under circumstances where it is not designed to function. Throughout participants' comments, we also observed indications of these situations. As one participant pointed out, part of the learning process is testing its limitations. Nevertheless, these findings support the idea that the relationship between trust and automation failures is a complex one, and many factors can influence this process [6]. Earlier, we reported that drivers who experienced an incident did not perceive these situations particularly risky [4]. We believe current results on trust support these findings such that experiencing an Autopilot incident does not necessarily cause significant reductions in trust. However, we should note

that these ratings don't necessarily represent drivers' trust immediately after experiencing an incident. Trust is a dynamic and evolving process [7], and while it may decrease after automation faults, gradually it recovers [15].

Trust in Summon was not influenced by whether participants experienced an incident or not. While there was a trend towards reduced levels of trust for Incident group, current data failed to support this hypothesis, partly due to sample size. Surprisingly, initial trust in Summon was strongly and negatively correlated with perceived risk. This suggests that perhaps failures mostly occurred during initial use of Summon which might have influenced initial trust. Nevertheless, we should note that Autopilot and Summon are qualitatively different automation systems both in terms of the consequences of failures and the level of complexity of the environments where these systems are used. Therefore, trust development process might be affected by different factors for these systems.

This work had several limitations. Unlike laboratory experiments, trust was not assessed immediately after the incidents, and the time interval between the last time the drivers experienced an incident and responded to the survey varies from person to person. A longitudinal study on how trust develops over time with autonomous vehicles would identify both fluctuations in trust and how drivers psychologically deal with automation failures. Also, while we observed that trust was associated with multiple factors, identifying exact mechanisms require further research. Trust evolves over time, and while trust influences reliance on automation, it is not the only factor [7]. Future research should examine the affective component of trust in autonomous cars. Our observations throughout this work have been that there is more than meets the eye when it comes to developing a trust relationship with people's own cars, where factors such as drivers' attitudes towards the designer (i.e. the brand or company producing the vehicle), public opinions and social influence might play an important role. Therefore, it is critical to develop an understanding of the concept of trust in personal automation such as personal cars.

VI. Conclusion

In this study, we examined trust in automation in the context of Autopilot and Summon. Overall Tesla drivers reported high levels of trust in these technologies. Trust was related to several attitudinal and behavioral factors, and experience shaped the level of trust in these technologies. While this work was an initial step towards understanding how trust plays a role in the real world use of autonomous vehicles, it showed that previous findings on trust in automation are applicable to real world cases as well. We hope these findings will help to understand drivers' trust in autonomous vehicles, as the concept of trust will be fundamental in an automated world.

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