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Autonomous Driving in the Real World: Experiences with Tesla Autopilot and Summon

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ABSTRACT
As autonomous driving emerges, it is important to understand drivers' experiences with autonomous cars. We report the results of an online survey with Tesla owners using two autonomous driving features, Autopilot and Summon. We found that current users of these features have significant driving experience, high self-rated computer expertise and care about how automation works. Surprisingly, although automation failures are extremely common they were not perceived as risky. The most commonly occurring failures included the failure to detect lanes and uncomfortable speed changes of the vehicle. Additionally, a majority of the drivers emphasized the importance of being alert while driving with autonomous features and aware of the limitations of the current technology. Our main contribution is to provide a picture of attitudes and experiences towards semi-autonomous driving, revealing that some drivers adopting these features may not perceive autonomous driving as risky, even in an environment with regular automation failures.

Author Keywords
Autonomous driving; ADAS; Human Factors; Automation failure; Questionnaire.

ACM Classification Keywords
H.1.2 User/Machine Systems: Human factors

INTRODUCTION
Autonomous driving is on the horizon and, in some cases, semi-autonomous features are now available on some models and types of vehicles. As an example of some of the most advanced features currently available, Tesla released its Autopilot and Summon features in October 2015 and January 2016, respectively. Autopilot is a system which provides lateral and longitudinal control and allows hands-free driving, in addition to other functionality such as automatic lane changing. Summon is a parking assistance system which allows drivers to park their cars from outside the vehicle [14].

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The release of these features allow for real world discussions of how people interact with these early autonomous features and how they are influencing driver perceptions and attitudes. Research has raised concerns regarding automated driving such as overreliance [4], reduced situational awareness [13, 5] and increased engagement with secondary tasks, diverting attention away from the road [3, 9]. Given these concerns are largely from laboratory research, it is important to understand whether such concerns are reflected in real world autonomous driving.

RELATED WORK
Many surveys have been conducted in the past to understand people's attitudes towards autonomous cars. Previous work showed that people are attracted to safety and convenience of self-driving cars but were concerned with the lack of control, liability, and cost [6]. The majority of people also have a priori acceptance of autonomous cars [10], yet opinions can be split [2]. A recent survey found that majority of people had positive attitudes towards autonomous cars but were concerned with aspects such as security and legal issues [7]. Similarly, another study found that most people had positive opinions about autonomous vehicles while expressing concerns regarding safety [11]. A weakness of these studies, however, is that they were unable to study the attitudes of people who had real world experience with autonomous driving.

In one study of real-life use of autonomous vehicles, Larsson [8] reported that adaptive cruise control (ACC) users experience frequent limitations of the system and the more they drive with ACC the more they become aware of the system limitations. The same survey also revealed that drivers experience mode errors and concludes that imperfect ACC may be better for driving safety because it keeps the drivers in the loop.

Our research extends these findings by looking at experiences with the next generation of semi-autonomous driving features which combine ACC with steering assistance. We wanted to understand how often drivers use these features, how often do they experience failures, and how does experience with these automation failures influence their attitudes towards the automation.

METHODOLOGY
We conducted an online survey with 162 Tesla Owners. The survey was distributed through online forums and social media during April-May 2016. The survey asked questions

about drivers' attitudes towards and experiences with two functionalities built into Tesla Model S cars: Autopilot and Summon. Questions covered frequency of use, satisfaction, ease of learning and knowledge related to Autopilot and Summon. Additionally, we asked participants to report unusual or unexpected behaviors they experienced while using these systems and what they consider a key aspect of safety. The average time to complete the survey was 9.6 minutes.

RESULTS

A total of 121 participants completed the survey fully. The demographics of the sample is summarized in Table 1. The sample was 94.2% male, and had significant driving experience with 89.3% reporting driving experience beyond 10 years. These drivers drive frequently with 79.3% reporting that they drive daily. Participants identified themselves mostly as above average and expert computer users. All means reported in the subsequent analysis correspond to 5-point Likert scales where 5 is high and 1 is low.

Participants reported very high levels of satisfaction with their cars (M = 4.91, SD = .43). Means and standard deviations for self-rated knowledge, ease of learning and importance of knowing how automation makes decisions are shown in Table 2. To summarize, participants reported that it is easy to learn the automated systems, they rated their knowledge level as above average, and importance of knowing how automation makes decisions as above average. In addition, the Autopilot display, the display on the dashboard showing information about the current state of Autopilot such as the detected vehicles on the roadway, was perceived as useful.

Age	**% (N = 121)**
16 - 20	3.3
21 - 24	2.5
25 - 34	18.2
35 - 44	25.6
45 - 54	23.1
55 - 64	14.0
65 or older	13.2
Computer Expertise	**% (N = 121)**
Novice	.8
Average	5.0
Above average	38.8
Expert	55.4

Table 1. The demographics of the sample.

	Autopilot		**Summon**	
	Mean	SD	Mean	SD
Knowledge	3.79	.82	3.54	.92
Ease of Learning	4.27	.72	3.97	.84
Importance	3.51	1.08	3.13	1.15
Usefulness of Autopilot Display	4.04	.71	-	-

Table 2. Descriptive statistics for self-rated knowledge, perceived ease of learning, importance of knowing how the system makes decisions, and usefulness of Autopilot display.

90.1% of the participants reported that they actively use Autopilot or have used it in the past. Likewise, 85.2% of the participants reported that they actively use the Summon feature or have used it in the past.

Participants use Autopilot quite frequently with 31.2% saying they use it "always" and 57.8% saying they use it "often". Participants use Summon less frequently with 49% saying they use it "rarely" and 22% saying "sometimes".

Automation Limitations and Failures

Of the Autopilot users, 62.4% reported that they have experienced at least one unexpected or unusual behavior from the car while in autonomous driving mode. Further, 13.8% reported that they have experienced at least two unexpected or unusual behaviors from the car. In total, participants reported 91 cases of automation events. Of the Summon users, 21.2% reported that they have experienced at least one unexpected or unusual behavior from the car while using the system. In total, participants reported 27 cases. Perceived risk involved in these events are shown in Figure 1 for Autopilot and Figure 2 for Summon.

Cases of Unexpected Automation Behaviors

Next, we analyzed the reported cases of unexpected automation behavior. For Autopilot, of the 91 cases analyzed, two major categories of limitations emerged. The first category involved issues with lane detection (74.4% of the cases). These problems included the car trying to take an exit ramp, swerving and veering due to failure to detect the lane, and trying to cross lanes for no apparent reason, sometimes even towards lanes where traffic flowed in the opposite direction. The second category involved problems with speed changes and the adaptive cruise control system. This category includes issues such as sudden braking or uncomfortable acceleration and deceleration (15.6% of the cases). Participants reported that speed related problems mostly occurred in the heavy traffic conditions. Almost all users reported that they took manual control over after the incident and most reported that they re-initiated autonomous driving once the situation that caused automation failure was over. In the majority of the 27 Summon cases, participants reported technical problems such as connection failures.

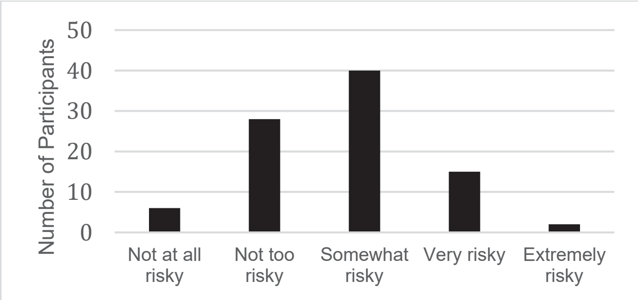

Figure 1. Perceived risk after experiencing an Autopilot failure.

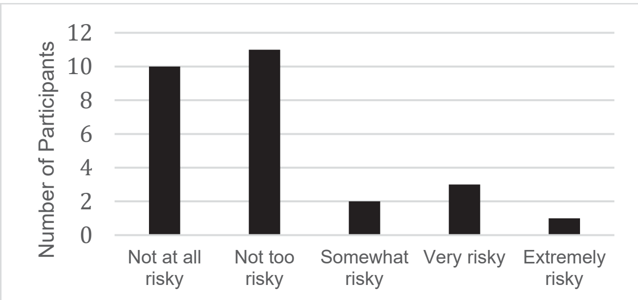

Figure 2. Perceived risk after experiencing a Summon failure.

Statistical Results

There were no differences between age groups in the measured variables, indicated by non-significant ANOVAs. There were also no differences between those who had an Autopilot failure (N=68) and those who did not (N=45) in measured variables, indicated by non-significant t-tests.

Perceived usefulness of Autopilot display was significantly correlated with satisfaction with the car, $r = .22$, $p = .019$, and the ease of learning, $r = .23$, $p = .017$, hinting at the possible contribution of the visual display to the learning process of Autopilot. It was also correlated with importance of knowing how Autopilot makes decisions, $r = .21$, $p = .031$. As expected, the Autopilot display can be used as a means to understand the decision-making process of the car and to obtain situation awareness.

For those who had an Autopilot failure (N=68), perceived risk of the situation was correlated only with importance of knowing how Autopilot makes decisions, $r = .24$, $p = .053$.

Safe Driving

Participants emphasized being alert at all times, paying attention to the road environment and keeping hands on the wheel while in autonomous driving mode. They also emphasized the importance of learning the limitations of the technology such as under which conditions the automation can fail. A critical question here is how drivers can learn the specific conditions in which automation is more likely to fail without trial and error? Or should trial and error be part of the learning process, as some participants suggested? We believe addressing this issue requires further research.

DISCUSSION

Based on the results, at first glance, the situation of semi-autonomous driving seems generally positive. Drivers seem to enjoy these technologies, and are aware of the limitations of Autopilot and Summon. In the comments, we observed that drivers were highly motivated to use these technologies safely and have not seen indications of the concerns raised in the past such as engaging with secondary tasks while using Autopilot.

Despite the relatively high frequencies of automation events, these drivers did not consider the automation to be particularly risky. We believe three factors might have contributed to this. First, even though the situations were unexpected, these users were aware that these are new technologies in early release, so they were quite accepting of events with the technology. Second, Tesla owners are unlikely to be representative of general drivers. Tesla drivers are early adopters with high comfort with technology, and are unusually devoted to the development of their vehicles. Third, none of the incidents reported involved a negative outcome, which may also be influencing their perception of risk. Relatively frequent exposure to small events may also be teaching these drivers to stay "in the loop" with the automation.

However, failure rates will decrease eventually and this may trigger different observations of driver performance. In almost all cases covered in the survey, participants reported that they successfully took control and drove manually until in a safe situation again. However, this may not happen always as studies show possible decrements in situational awareness during autonomous driving [12, 13]. While the argument can be made that imperfect automation will keep the drivers in the loop [8], it is unreasonable to think that automation will deliberately remain imperfect. Over time, autonomous features will increase in reliability and functionality and this, unfortunately, does present a risk for a lack of situation awareness by drivers who are increasingly "out of the loop". Further, the drivers in this study were well experienced and very comfortable with technology and may have responded more confidently when experiencing these failures.

Based on the incidents reported, currently, lane keeping is an important issue, especially in situations where lane markings are missing, or the car cannot correctly identify obstacles on the road environment. For the parking system, Summon, the most commonly experienced problem was the operation stopping due to a technical failure such as a connection problem. An interesting point is that with the rise of semi-autonomous driving, the role of the driver shifts from the active driver to a supervisory role [1]. This new role can place demands of different nature on the driver. For example, in addition to monitoring the road environment similar to manual driving, the driver also has to monitor whether lane markings are clear or not, or more importantly, whether the car can correctly identify the lane. This and other limitations of the automation might not be always obvious, therefore the communication between automation and the driver becomes crucial in order to maintain situation awareness. The correlations between perceived usefulness of the Autopilot display and ease of learning and importance of knowing how Autopilot makes decisions also indicate the importance of driver-vehicle communication in the autonomous driving context. Further research should address these issues by studying the role of automation displays in obtaining situation awareness in autonomous vehicles.

A limitation of the current study is that our sample is not representative of the general driver population. Considering the computer expertise and knowledge level about autonomous driving functionality, our participants are likely early adopters. Therefore, we must be cautious generalizing our findings. While the focus of this study was on two particular systems, Tesla Autopilot and Summon, we believe the results obtained and issues revealed are applicable to other systems as well.

CONCLUSION

In this paper, we examined the current state of semi-autonomous driving in the real world. Our survey data showed that current users of autonomous driving features of Tesla cars use Autopilot frequently, they are knowledgeable about automation and they find it easy to learn. The frequency of automation failure rate was high; however, most participants did not perceive these incidents as posing a significant risk. Our main contribution is to provide insights into the real world phenomenon of autonomous driving in its early stages, as first generation technology becomes available in the market.

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